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16. ABSTRACT The report discusses the control of accidental releases of hydrogen cyanide (HCN) to the atmosphere. HCN has an IDLH (immediately dangerous to life and health) concentration of 50 ppm, making it an acute toxic hazard. Reducing the risk associated with an accidental release of HCN involves identifying some of the potential causes of accidental releases that apply to the process facilities that use HCN. The manual identifies examples of potential causes and measures that may be taken to reduce the accidental release risk. Such measures include recommendations on: plant design practices; prevention, protection, and mitigation technologies; and operation and maintenance practices. Conceptual cost estimates of example prevention, protection, and mitigation measures are provided. The accidental release of a toxic chemical at Bhopal, India, in 1984 was a milestone in creating an increased public awareness of toxic release problems. As a result of other, perhaps less dramatic, incidents in the past, portions of the chemical industry were aware of this problem long before Bhopal. These same portions of the industry have made advances in this area. Interest in reducing the probability and consequences of accidental toxic chemical releases that might harm workers within a process facility and people in the surrounding community prompted this and other similar manuals.

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VOLUME 10: CONTROL OF ACCIDENTAL RELEASES OF HYDROGEN CYANIDE

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ABSTRACT

The accidental releases of a toxic chemical at Bhopal, India in 1984 was a milestone in creating an increased public awareness of toxic release problems. As a result of other, perhaps less dramatic incidents in the past, portions of the chemical industry were aware of this problem long before these events. These same portions of the industry have made advances in this area. Interest in reducing the probability and consequences of accidental toxic chemical releases that might harm workers within a process facility and people in the surrounding community prompted the preparation of this manual and a planned series of companion manuals addressing accidental releases of toxic chemicals.

Hydrogen cyanide has an IDLH (Immediately Dangerous to Life and Health) concentration of 50 ppm, which makes it an acute toxic hazard.

Reducing the risk associated with an accidental release of hydrogen cyanide involves identifying some of the potential causes of accidental releases that apply to the process facilities that use hydrogen cyanide. In this manual, examples of potential causes are identified as are specific measures that may be taken to reduce the accidental release risk. Such measures include recommendations on plant design practices, prevention, protection and mitigation technologies, and operation and maintenance practices. Conceptual cost estimates of example prevention, protection, and mitigation measures are provided.

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

Increasing concern about the potentially disastrous consequences of accidental releases of toxic chemicals resulted from the Bhopal, India accident of December 3, 1984, which killed approximately 2,000 people and injured thousands more. A toxic cloud of methyl isocyanate was released. Concern about the safety of process facilities handling hazardous materials increased further after the accident at the Chernobyl nuclear power plant in the Soviet Union in April of 1986.

While headlines of these incidents have created the current awareness of toxic release problems, there have been other, perhaps less dramatic incidents in the past. Interest in reducing the probability and consequences of accidental toxic chemical releases that might harm workers within a process facility and people in the surrounding community prompted the preparation of this manual and a planned series of companion manuals.

Hydrogen cyanide is a major commercial chemical and a low boiling toxic liquid or gas at typical ambient conditions. Historically, there have been few significant releases of hydrogen cyanide in the United States. However, there have been a number of deaths, mostly of chemical plant workers, that have resulted from accidental releases of hydrogen cyanide.

1.2 PURPOSE OF THIS MANUAL

The purpose of this manual is to provide technical information about hydrogen cyanide and specifically about prevention, protection, and mitigation measures for accidental releases of hydrogen cyanide. The manual addresses technological and procedural prevention, protection, and mitigation measures associated with the storage, handling, and process operations involving hydrogen cyanide as it is used in the United States. This manual does not address uses of hydrogen cyanide not encountered in the United States.

This manual is intended as a summary manual for persons charged with reviewing and evaluating the potential for releases of hydrogen cyanide at facilities that use, store, handle, or manufacture hydrogen cyanide. It is not intended as a specification manual, and in fact refers the reader to additional technical manuals and other information sources for more complete information on the topics discussed. Other information sources include manufacturers and distributors of hydrogen cyanide, and technical literature on design, operation, and loss prevention in facilities handling toxic chemicals.

1.3 SOURCES AND USES OF HYDROGEN CYANIDE

Two processes for manufacturing hydrogen cyanide (HCN) account for most of the total hydrogen cyanide produced in this country. The most widely used process produces hydrogen cyanide by reacting natural gas (methane), ammonia and air. A second widely used process (which is actually a variation of the first process) is called the BMA process and produces hydrogen cyanide by reacting methane with ammonia. In addition to direct manufacture, hydrogen cyanide is also produced as a by-product of acrylonitrile manufacture. In 1983 it was estimated that 930 million pounds of hydrogen cyanide were manufactured. At that time, the projected demand for 1988 was 1,186 million pounds (1).

The major use of hydrogen cyanide in the U.S., as of 1983, was for the production of adiponitrile. Adiponitrile is used primarily as an intermediate for hexamethlyenediamine, which is a principal ingredient for nylon-6,6. Another major use of hydrogen cyanide is for the production of acetone cyanohydrin which is used almost exclusively as an intermediate for methyl methacrylate. Methyl methacrylate is used to manufacture polymethyl methacrylate (Plexiglas®). Hydrogen cyanide is also used in the manufacture of cyanuric chloride (an intermediate in pesticide manufacturing), miscellaneous chelating agents, sodium cyanide, and a number of other chemical products. In 1983, the uses of hydrogen cyanide in the U.S. were: adiponitrile, 38 percent; methyl methacrylate, 35 percent; cyanuric chloride, 10 percent; chelating agents 7 percent; sodium cyanide, 5 percent; other uses, 5 percent (1).

In the U.S., hydrogen cyanide is stored in small cylinders (e.g., 150 lb), railroad tank cars, and bulk storage tanks.

1.4 ORGANIZATION OF THE MANUAL

The remainder of this manual presents technical information on specific hazards and categories of hazards and their control as they relate to hydrogen cyanide. As stated previously, these are examples only and are representative of only some of the hazards that may be related to accidental releases.

Section 2 discusses physical, chemical and toxicological properties of hydrogen cyanide. Section 3 describes the types of facilities which manufacture and use hydrogen cyanide in the United States. Section 4 discusses process hazards associated with these facilities. Hazard prevention and control are discussed in Section 5. Costs of example storage and process facilities reflecting different levels of control through alternative systems are also presented in Section 5. The examples are for illustration only and do not necessarily represent a satisfactory alternative control option in all cases. Section 6 presents a reference list. Appendix A is a glossary of key technical terms that might not be familiar to all users of the manual. Appendix B presents selected conversion factors between metric (SI) and English measurement units.

SECTION 2
CHEMICAL CHARACTERISTICS

This section of the manual describes the physical, chemical, and toxicological properties of hydrogen cyanide as they relate to accidental release hazards.

2.1 PHYSICAL PROPERTIES

Anhydrous hydrogen cyanide is a colorless or pale yellow liquid with a mild odor similar to bitter almonds. The liquid boils at 78.3°F at 1 atmosphere of pressure and forms a colorless, flammable, toxic gas. The physical properties of anhydrous hydrogen cyanide are listed in Table 2-1.

Hydrogen cyanide is completely soluble in water. The gas is slightly less dense than air, although a mixture of hydrogen cyanide in moist air may stay near ground level. Liquid hydrogen cyanide will expand slightly with heating. As a result, liquid-full equipment can pose a hazard (although as will be seen, the potentially greater danger from trapping liquid hydrogen cyanide in equipment is the potential for polymerization). A liquid-full vessel is a vessel that is not vented and is filled with liquid hydrogen cyanide with little or no vapor space present above the liquid. A liquid-full line is a section of pipe that is sealed off at both ends and is full of liquid hydrogen cyanide with little or no vapor space. In these situations, there is no room for thermal expansion of the liquid, and temperature increases can result in containment failure.

2.2 CHEMICAL PROPERTIES AND REACTIVITY

Three chemical properties of hydrogen cyanide that contribute to the potential for an accidental release of the chemical are (2,3):

TABLE 2-1. PHYSICAL PROPERTIES OF HYDROGEN CYANIDE

		Reference
CAS Registry Number	74-90-8	
Chemical Formula	HCN	
Molecular Weight	27.03	
Normal Boiling Point	78.3 °F @ 1 atm	2
Melting Point	8.17 °F	3
Liquid Specific Gravity (H_2O=1)	0.6884 @ 68 °F	2
Vapor Specific Gravity (air=1)	0.947 @ 88 °F	2
Vapor Pressure	0.348 atm @ 32°F	2
Vapor Pressure Equation:		

$$\log Pv = A - \frac{B}{T+C}$$

where: Pv = vapor pressure, mm Hg
T = temperature, °C
A = 7.5282, a constant
B = 1329.5, a constant
C = 260.4, a constant

Liquid Viscosity	0.2014 centipoise @ 68 °F	2
Solubility in Water	Complete	
Specific Heat at Constant Pressure	16.94 Btu/(lbmole-°F) @ 62.4 °F	3
Latent Heat of Vaporization	10,834 Btu/lbmole @ 77 °F	3

(Continued)

TABLE 2-1 (Continued)

			Reference
Liquid Surface Tension		17.2 dynes/cm @ 77 °F	3
Heat of Combustion		287,000 Btu/lbmole	3
Autoignition Temperature		1,000 °F	3
Explosive Range, Volume % in air @ 1 atm and 68 °F	min.	6	
	max.	41	
Flashpoint, TCC (ASTM D-56)		0 °F	3
Additional properties useful in determining other properties from physical property correlations.			
Critical Temperature		362.2 °F	3
Critical Pressure		53.2 atm	3
Critical Density		12.2 lb/ft^3	3

- Hydrogen cyanide is flammable in air at concentrations from 6 percent to 41 percent hydrogen cyanide.

- The addition of alkaline chemicals, water and/or heat may promote self-polymerization and decomposition of hydrogen cyanide. The self-polymerization reaction is exothermic and the heat released will promote further polymerization. The heat generation will also result in the decomposition of hydrogen cyanide into ammonia and formate. The pressure rise from polymerization/decomposition reactions can become explosive. Small amounts of acid such as sulfuric or phosphoric will help to stabilize the hydrogen cyanide against polymerization.

- The addition of large quantities of acid (over 15% by weight of concentrated sulfuric acid) can cause rapid decomposition of hydrogen cyanide. This decomposition is highly exothermic. When sulfuric acid is involved the decomposition by-products will be sulfur dioxide and carbon dioxide.

2.3 TOXICOLOGICAL AND HEALTH EFFECTS

Hydrogen cyanide is highly toxic by ingestion, inhalation and skin adsorption. It is a true noncumulative protoplasmic poisons (i.e., it can be detoxified readily). Hydrogen cyanide combines with those enzymes at the blood/tissue interfaces that regulate oxygen transfer to the cellular tissues. Unless the cyanide is removed, death results through asphyxia. The warning signs of hydrogen cyanide poisoning include: dizziness, numbness, headache, rapid pulse, nausea, reddened skin, and blood shot eyes. More prolonged exposure can cause vomiting and labored breathing followed by unconsciousness, cessation of breathing, rapid weak heart beat, and death. Severe exposure (by inhalation) can cause immediate unconsciousness; this rapid knockdown power

without any irritation or detectable odor to some people makes hydrogen cyanide more dangerous than other materials of comparable toxicity (e.g., hydrogen sulfide). Table 2-2 presents a summary of some of the relevant exposure limits for hydrogen cyanide. Table 2-3 presents a summary of predicted human health effects of exposure to various concentrations of hydrogen cyanide.

TABLE 2-2. EXPOSURE LIMITS FOR HYDROGEN CYANIDE

Exposure Limit	Concentration (ppm)	Description	Reference
IDLH	50	The concentration defined as posing immediate danger to life and health (.e., causes irreversible toxic effects for a 30-minute exposure).	5
PEL	10	A time-weighted 8-hour exposure to this concentration as set by the Occupational Safety and Health Administration should result in no adverse effects for the average healthy, male worker.	6
LCLo	178	This concentration is the lowest published lethal concentration for a human over a 10-minute exposure.	6

TABLE 2-3. PREDICTED HUMAN HEALTH EFFECTS OF EXPOSURE TO VARIOUS CONCENTRATIONS OF HYDROGEN CYANIDE

ppm	Predicted Effect
2-5	Odor threshold.
20	Causes slight symptoms including headache and dizziness after several hours.
50	Causes disturbances within an hour.
100	Dangerous for exposures of 30-60 minutes.
300	Rapidly fatal unless prompt, effective first aid is administered.

Source: Adapted from Reference 2.

SECTION 3
FACILITY DESCRIPTIONS AND PROCESS HAZARDS

This section provides brief descriptions of the uses of hydrogen cyanide in the United States. Major hazards of these processes as they relate to accidental releases are discussed in Section 4. Preventive measures associated with these hazards are discussed in Section 5.

3.1 HYDROGEN CYANIDE MANUFACTURE

Two processes for manufacturing hydrogen cyanide account for most of the total hydrogen cyanide produced in this country. The most widely used process is one that produces hydrogen cyanide by reacting natural gas (methane), ammonia and air. A second widely used process (which is actually a variation of the first process) is called the BMA process which produces hydrogen cyanide by reacting methane with ammonia. In addition to direct manufacture, hydrogen cyanide is also produced as a by-product of acrylonitrile manufacture.

A schematic diagram of a hydrogen cyanide manufacturing process is presented in Figure 3-1. In this process ammonia, methane (or natural gas) and air are preheated to about 750 to 900°C, mixed and sent to a packed bed reactor. The reactor is typically packed with a catalytic wire gauze composed of platinum or a platinum rhodium composite (7). The exit gas from the reactor contains a mixture of hydrogen cyanide, ammonia, and water vapor (a by-product of the reaction). As illustrated in Figure 3-1, this crude product mixture is sent to an ammonia absorption column where the ammonia is absorbed in an ammonium phosphate solution (8). Most of the hydrogen cyanide exits in the gas phase where it is absorbed, washed and treated with sulfur dioxide as an inhibitor to prevent polymerization. The ammonium phosphate solution is sent through a series of processing operations where the ammonia is recovered and recycled back to the reactor.

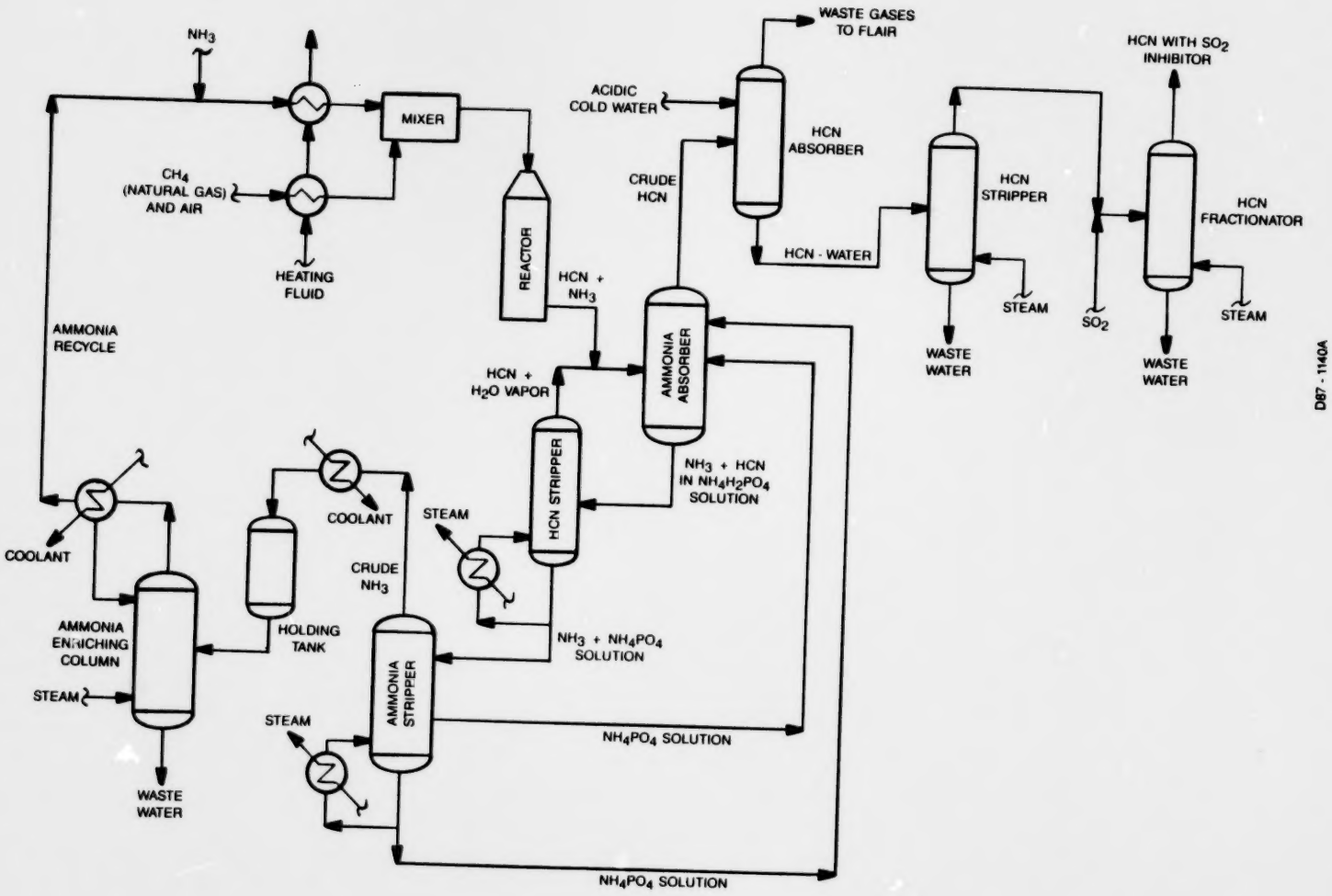


Figure 3-1. Hydrogen cyanide manufacturing process. Adapted from References 2, 8 and 9.

The reaction that produces hydrogen cyanide is endothermic. To provide the necessary heat of reaction, forty percent or more of the ammonia and methane fed to the process are intentionally oxidized in the reactor vessel. The heat input from the oxidation of the methane and ammonia balanced by the heat requirements of the hydrogen cyanide reaction will result in a normal reaction temperature of about 2000 to 2200°F (9).

High hazard areas in the cyanide manufacturing process include the following:

- Cyanide reactor;
- Hydrogen cyanide absorber;
- Hydrogen cyanide stripper; and
- Hydrogen cyanide fractionator.

The cyanide reactor is critical because of the high temperatures that are involved. Overheating the reactor could result in uncontrollable combustion reactions or explosions (10). These uncontrollable combustion reactions or explosions could result in the physical breakdown of the reactor vessel by thermal fatigue or overpressure. There are three possible causes of overheating. They include:

- Poor heat distribution within the reactor bed, resulting in hot spots;
- Overheating raw materials before they enter the cyanide reactor; or
- Loss of composition or quantity control of raw material feeds.

Hot spot formation within the reactor can result in catalyst breakdown or physical deterioration of the reactor vessel (10). If the chemical performance of the catalyst is destroyed then no reaction will occur. If the endothermic cyanide reaction has ceased, then the reactor is likely to overheat. In addition to the potential causes of overheating listed above, it should be noted that iron is a decomposition catalyst for hydrogen cyanide and ammonia under the conditions present in the hydrogen cyanide reactor. Exposed iron surfaces in the reactor or reactor feed system can result in uncontrolled decomposition, which could result in an accidental release by overheating and overpressure.

Only a small inventory of hydrogen cyanide will be present in the cyanide reactor. Therefore, catastrophic failure of the cyanide reactor is not likely to directly result in the release of large quantities of hydrogen cyanide. However, such failure could result in damage to other portions of the system where larger quantities of hydrogen cyanide are present.

The hydrogen cyanide absorber, stripper and fractionator are high hazard areas because they contain inventories of concentrated hydrogen cyanide. All of the associated pumps, piping and fittings for these systems are also high hazard areas. Controlling the pH of these systems is important since the vapor pressure of hydrogen cyanide is dependent upon pH. A system designed for hydrogen cyanide vapor pressure within one pH range may not be able to handle the increased cyanide vapor pressure at a lower pH. Reliable pH control is particularly important at the hydrogen cyanide fractionator where acid is intentionally added as a stabilizer to the feed stream. The quantity of acid that is added at this point is very small. However, the potential still exists for a loss of acid flow control. Large excesses of acid can result in a violent hydrogen cyanide decomposition reaction.

The ammonia recovery portion of the hydrogen cyanide manufacturing process does not contain large quantities of hydrogen cyanide. However, inventories of ammonia are present throughout this portion of the system.

Therefore a potential for an accidental release of ammonia exists in this section of the process.

3.2 HYDROGEN CYANIDE CONSUMPTION

The major use of hydrogen cyanide in the U.S. today is for the production of adiponitrile. Adiponitrile is used primarily as an intermediate for hexamethlyenediamine, which is a principal ingredient for nylon-6,6 (1). Another major use of hydrogen cyanide is for the production of acetone cyanohydrin which is used almost exclusively as an intermediate for methyl methacrylate. Methyl methacrylate is used to manufacture polymethyl methacrylate (Plexiglas®). Hydrogen cyanide is also used in the manufacture of cyanuric chloride (an intermediate in pesticide manufacturing), miscellaneous chelating agents, sodium cyanide, and a number of other chemical products. Table 3-1 lists a variety of products that might be manufactured using hydrogen cyanide.

This subsection summarizes some of the major technical features of process facilities that might use hydrogen cyanide in the U.S.

3.2.1 Manufacture of Adiponitrile

Adiponitrile is commercially manufactured by several different processes all of which begin with a different hydrocarbon raw material. Hydrogen cyanide is found only in those processes that use butadiene as a starting material. In some butadiene-based processes, sodium cyanide is used as the raw material (11). In other butadiene-based processes hydrogen cyanide is used as the raw material. Figure 3-2 illustrates a process that uses hydrogen cyanide to manufacture adiponitrile.

In this process, hydrogen cyanide and a slight excess of butadiene are fed to a reactor packed with nickel catalyst. The reaction is carried out at 212°F and sufficient pressure to keep the reactants in solution (12). The product mixture contains 2-methyl-3-butenenitrile, 3-pentenenitrile, and

TABLE 3-1. TYPICAL USES OF HYDROGEN CYANIDE

Acetone cyanahydrin
Adiponitrile
Acrylonitrile
Aminopolycarboxylic acids
Barium cyanide
Beta-amines
Cyanuric chloride
Diaminomaleonitrile
Lactic acid
Methionine
Sodium cyanide
Tertiary alkyl amines

Source: Adapted from Reference 14.

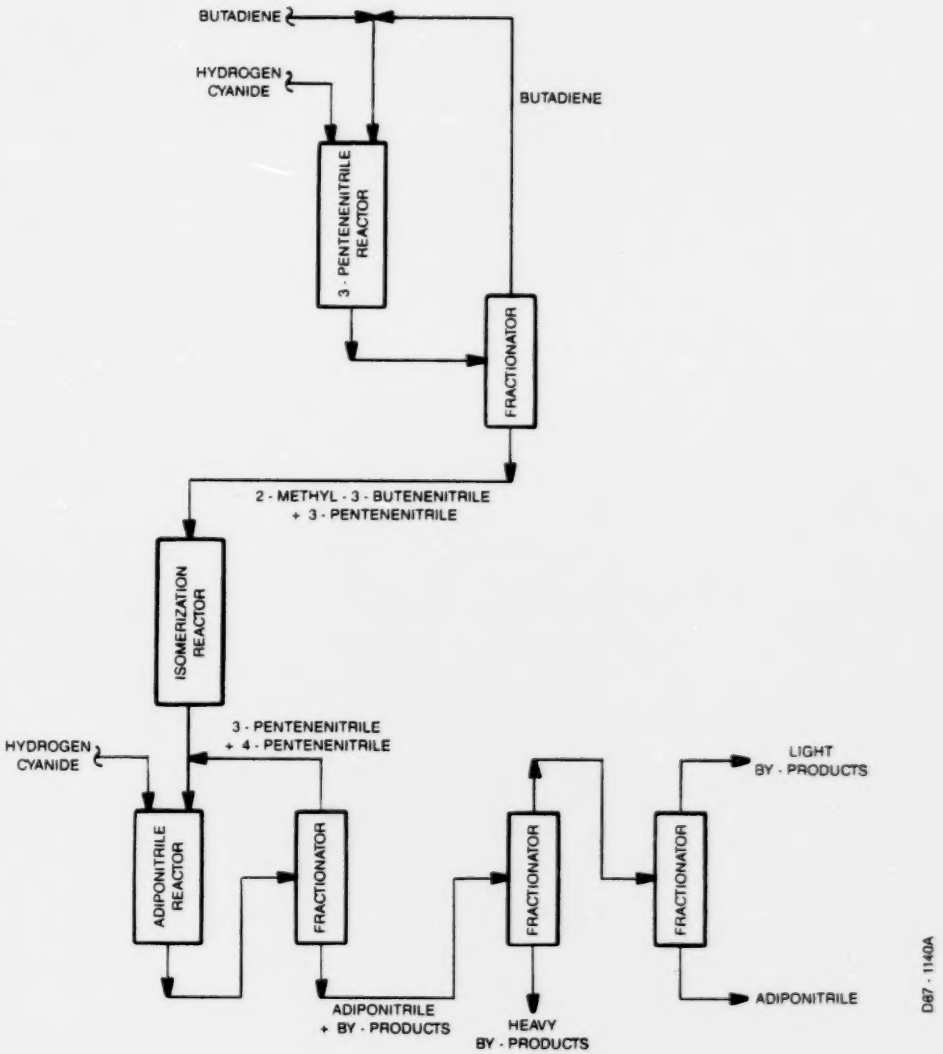


Figure 3-2. Manufacturing process for adiponitrile.

unreacted butadiene. The unreacted butadiene is separated from the product stream and recycled back to the reactor.

The fractionated product stream from the first hydrocyanation reactor is passed through a nickel catalyst bed where an isomerization reaction converts the 2-methyl-3-butenenitrile to 3-pentenenitrile and a small amount of 2-pentenitrile (13). The 3-pentenenitrile is then passed through another nickel catalyst bed along with hydrogen cyanide to produce adiponitrile. Unreacted pentenenitrile is separated from the product stream by distillation and recycled back to the reactor. The crude adiponitrile is purified by distillation.

The portions of the process that are of concern when considering a hydrogen cyanide release are the two hydrocyanation reactors and the hydrogen cyanide feed and storage system. The hydrocyanation reactors are run with an excess of olefin and thus the hydrogen cyanide is completely consumed by reaction. Both of these reactions are exothermic and thus there is the potential for a loss of temperature control and an accidental release by overpressure.

The hydrocyanation reactions are carried out at relatively mild conditions (around 212°F and 100 to 200 psia). A loss of temperature control would probably not result in high enough temperatures to structurally fatigue the reaction equipment. The major concern with a loss of temperature control would be the potential for vaporization of unreacted hydrogen cyanide within the reactor. This would result in an increase of pressure in the reactor. The consequences of such an increase would depend upon the ability of the pressure relief system to handle the vaporized hydrogen cyanide. Once the hydrogen cyanide was vaporized the hydrocyanation reaction would cease and no additional heat would be generated. The situation is, therefore, self correcting. There may be conditions under which loss of temperature control would result in a polymerization-decomposition of hydrogen cyanide.

Hydrogen cyanide storage and feed systems are of concern because of the relatively large inventory of hydrogen cyanide. Leaks from valves, fittings, pumps, and storage vessels are of concern.

3.2.2 Manufacture of Acetone Cyanohydrin/Methyl Methacrylate

Hydrogen cyanide can be combined with acetone to produce acetone cyanohydrin which in turn can be combined with methanol to form methyl methacrylate. As mentioned in the introduction to this subsection, almost all of the acetone cyanohydrin produced in this country is carried on to methyl methacrylate. Methyl methacrylate is also produced by routes that do not use hydrogen cyanide (15).

Figure 3-3 illustrates the acetone cyanohydrin production portion of a methyl methacrylate process that utilizes hydrogen cyanide (16). In this process, hydrogen cyanide, acetone and a catalyst are fed to a continuous stirred tank reactor to form acetone cyanohydrin. The reaction catalyst may be sodium hydroxide or some other alkaline metal salt. The reaction is run at a temperature between 70°F and 160°F. The reaction mixture is fed to a second stirred tank where sulfuric acid is added to quench the reaction. The acetone cyanohydrin is purified by first decanting off the catalyst and then distilling off unreacted raw materials.

The purified acetone cyanohydrin is then converted to methacrylamide sulfate by the addition of sulfuric acid. Methanol in an aqueous solution is then added along with the methacrylamide sulfate to a multistaged reactor where methyl methacrylate is formed. Several purification steps complete the manufacturing process.

The high hazard area of this process with regard to preventing an accidental release of hydrogen cyanide is the acetone cyanohydrin production portion of the process.

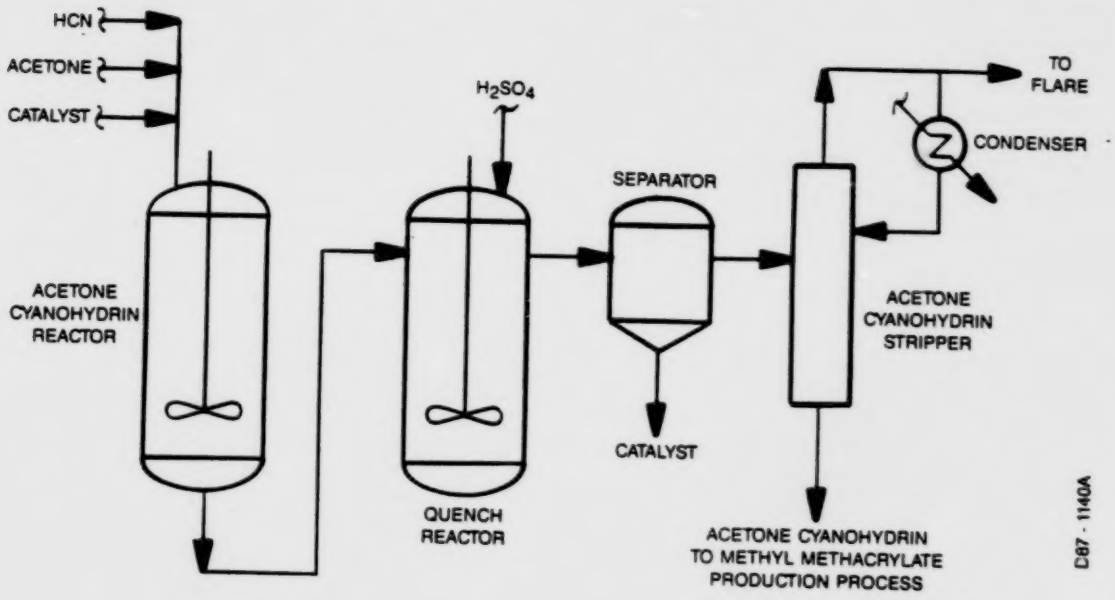


Figure 3-3. Manufacturing process for acetone cyanohydrin.

The first potentially hazardous location is the acetone cyanohydrin reactor. The inventory of hydrogen cyanide in the reactor will be relatively small. However, if the flow of acetone to the reactor were to cease, the conditions within the vessel would promote hydrogen cyanide polymerization-decomposition. The presence of excess hydrogen cyanide as well as inadequate mixing of the hydrogen cyanide with the acetone could also lead to polymerization-decomposition of the cyanide. Polymerization-decomposition could lead to overpressure or overheating in the reactor and result in an accidental release of hydrogen cyanide. Thus, control of flow, composition, mixing and temperature are all important in this reactor.

The reaction quenching vessel is a second potentially hazardous portion of this process. Failure to sufficiently quench the reaction with acid could result in a reversal of the reaction back to hydrogen cyanide and acetone. Acetone cyanohydrin will convert back to hydrocyanic acid and acetone if the pH is above a certain level. One source recommends that the pH for storage of acetone cyanohydrin not exceed 3 or 4, and the pH under more rigorous conditions such as those found in a distillation operation should not exceed 2 (17). The potential hazard, therefore, is that insufficient pH adjustment will result in acetone cyanohydrin decomposition in the stripping column. This would result in a significant increase in the flow of material to the flare. This increase in flow could disrupt the performance of the flare and result in an accidental release of hydrogen cyanide. Additionally, high levels of hydrogen cyanide in the stripping column could result in polymerization- decomposition.

The other major area of concern in this process is the hydrogen cyanide storage and feed system. The potential for an accidental release of hydrogen cyanide would be high because of the relatively large inventories.

3.2.3 Manufacture of Cyanuric Chloride

Cyanuric chloride is used for the production of triazine-based herbicides. It is manufactured in a two-step process. In the first step chlorine and hydrogen cyanide are reacted to form cyanogen. Cyclic trimerization of the cyanogen yields cyanuric chloride (18). Another method for the production of cyanuric chloride involves a single step fluidized bed process (19).

Very little hydrogen cyanide would be present in the reaction or purification sections of a cyanuric chloride manufacturing facility. The initial cyanuric reaction between hydrogen cyanide and chlorine will proceed rapidly, leaving little inventory of hydrogen cyanide in the reactor. The primary area of concern from the perspective of an accidental release of hydrogen cyanide would be the initial hydrogen cyanide storage and handling facility. Pumps, valves, piping, and vessels that are dedicated to hydrogen cyanide service would be of particular concern.

3.2.4 Manufacture of Sodium Cyanide

Sodium cyanide is usually produced by reacting hydrogen cyanide with a sodium hydroxide solution. Such manufacturing operations are often located directly down stream from a hydrogen cyanide manufacturing process. An example of a continuous sodium cyanide manufacturing process is presented in Figure 3-4 (20). In this process aqueous sodium hydroxide and gaseous hydrogen cyanide are fed to a vessel that functions as a reactor, evaporator and crystallizer, where they react to form sodium cyanide.

The reaction vessel contains aqueous sodium cyanide with a small amount of unreacted, excess sodium hydroxide. The sodium hydroxide is fed to the top of the reaction vessel while the hydrogen cyanide is fed to a recirculation loop at the bottom of the vessel. As the two reactants mix in a countercurrent fashion, they react to form sodium cyanide. The reactor is kept under partial vacuum. The reduced pressure lowers the boiling point of the

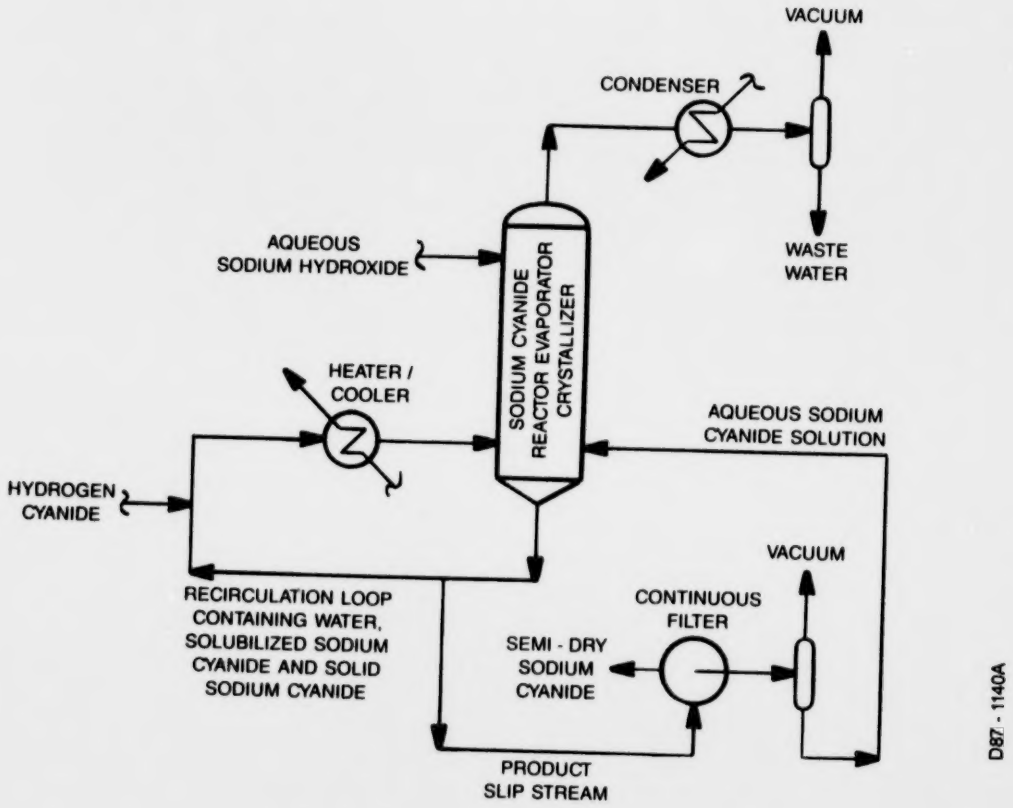


Figure 3-4. Sodium cyanide manufacturing process (20).

solution. The heat of reaction is removed by allowing water to boil off from the solution. The temperature of the mixture is therefore kept at its boiling point. As the reaction proceeds and water is removed, some of the sodium cyanide crystallizes out of solution. A product slip stream is withdrawn from the reactor recirculation loop and the crystallized sodium cyanide crystals are filtered out and dried. The filtrate is returned to the reaction vessel.

There are two issues of concern when operating a sodium cyanide manufacturing operation. The first concern is that hydrogen cyanide will polymerize before the reaction with sodium hydroxide occurs. The conditions in the reactor are favorable for polymerization if insufficient quantities of sodium hydroxide are present or if there is incomplete mixing of the hydrogen cyanide with the sodium hyroxide. The second concern is that sodium cyanide will hydrolyze to hydrogen cyanide and sodium formate. This reaction is very dependent upon temperature and can become significant at temperatures above 160 to 180°F (20).

Both of the problems listed above could be of concern from the perspective of accidental release prevention. The formation of polymerized cyanide could clog pumps and lines which could lead to an accidental release by overpressuring positive displacement pumps or overheating the contents of centrifugal pumps. Additionally, the polymerization reaction is exothermic. The heat generated by the reaction could result in excessive pressures and could contribute to additional polymer formation. Significant hydrolysis of sodium cyanide would lead to the formation of unexpected quantities of hydrogen cyanide which could result in overpressurization of the pump or overloading of the vacuum system; both of which could lead to an accidental release of hydrogen cyanide.

As with all processes that handle hydrogen cyanide, the hydrogen cyanide storage and feed system is of concern because of the relatively large inventory. A breach of containment within the hydrogen cyanide feed and storage system could result in an accidental release of the chemical.

3.3 STORAGE AND TRANSFER

When a facility uses large quantities of hydrogen cyanide, the hydrogen cyanide is either produced on site or is unloaded from a rail car into stationary storage.

Figure 3-5 shows a potential design for a hydrogen cyanide tank car unloading facility. The basic components of such a facility include nitrogen blanketing with pressure relief, grounding cables with clamps, special high-pressure piping and hoses for hookups of both hydrogen cyanide and nitrogen systems, tank level measuring device, tank car "come-along" for accurate positioning, wheel chocks, and derailers.

Figure 3-6 shows a potential design for a hydrogen cyanide storage tank. The basic components of such a system are temperature and pressure recorders and alarms, pressure relief to a flare or other treatment system, sulfuric acid addition system, liquid level measuring device with alarm, cooling system and diked enclosure.

The primary hazard associated with the storage of hydrogen cyanide is the potential for self polymerization. As described in Section 2-2, self polymerization can result in rapid temperature and pressure increases in a storage system and can result in a breach of containment. Several safety precautions concerning the prevention of polymerization will be discussed in Subsection 5.3.1.

Additional hazards associated with hydrogen cyanide storage include the potential for overfilling, corrosion, and contamination caused by backflow of process materials into the storage tank. Additionally, loss of tank refrigeration could result in overpressure due to thermal expansion of both the liquid and gaseous hydrogen cyanide. Such an overpressure would probably result in the discharge of hydrogen cyanide through the pressure relief device. The ultimate consequence of such a release will depend upon the ability of the hydrogen cyanide containment and protection system (e.g. a flare or scrubber) to handle such a load.

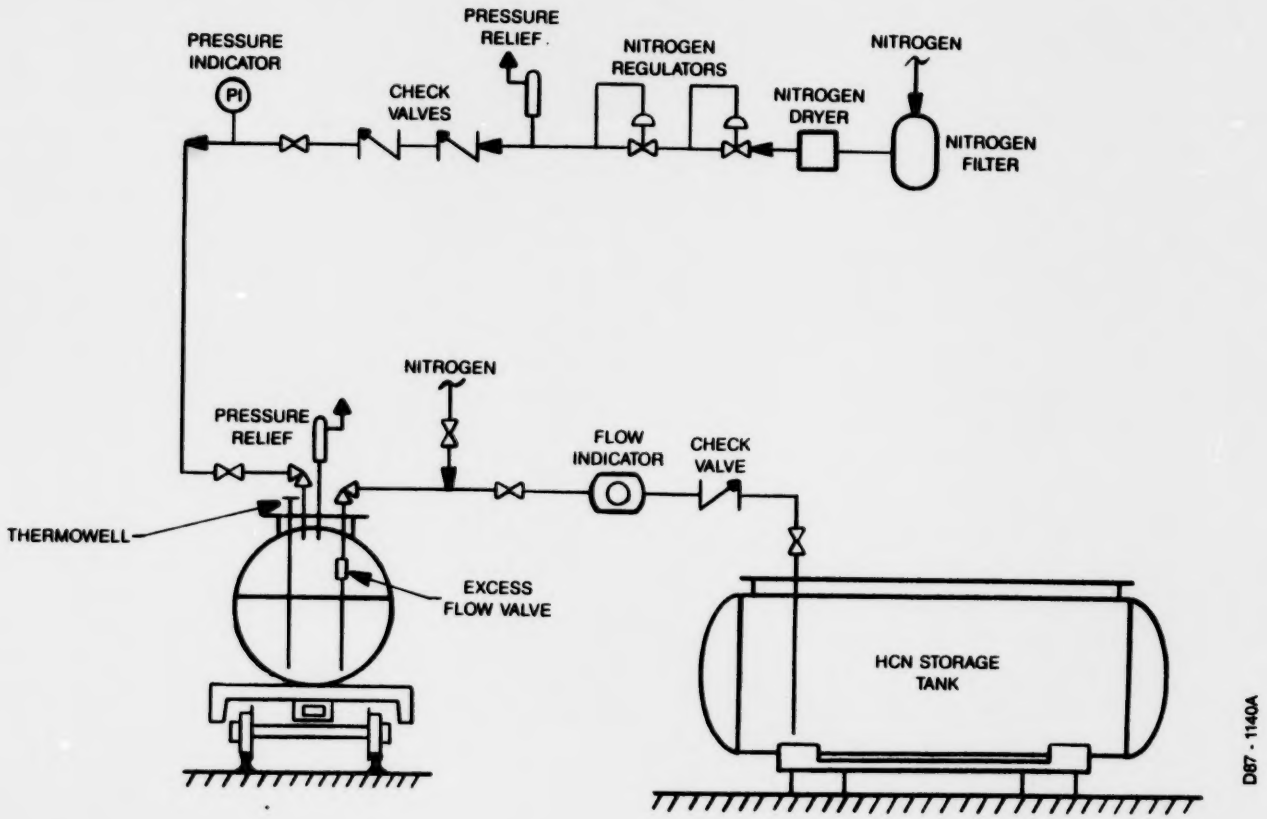


Figure 3-5. Example diagram of hydrogen cyanide tank car unloading facility. Adapted from Reference 3.

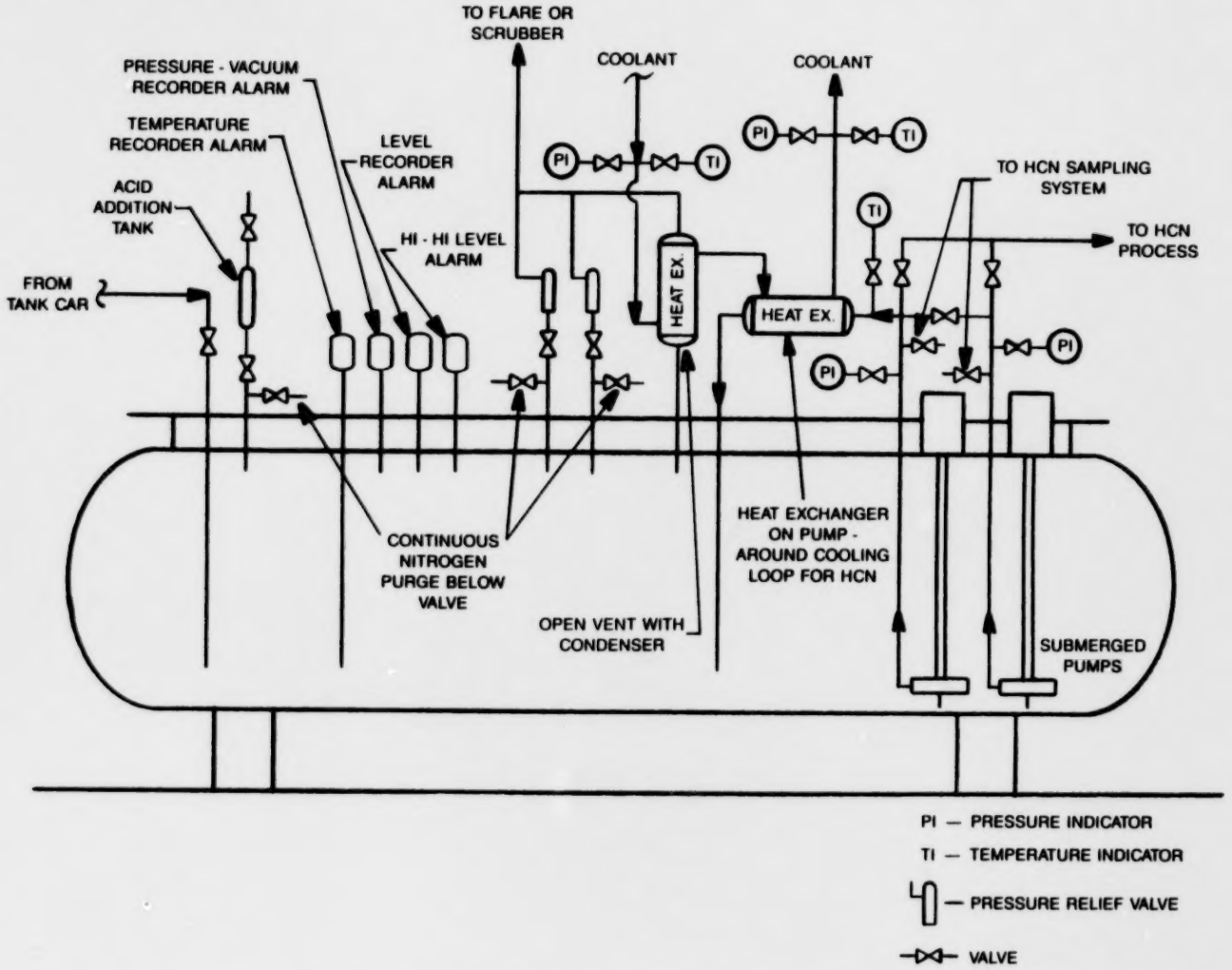


Figure 3-6. Example diagram of hydrogen cyanide storage facility. Adapted from Reference 3.

SECTION 4
PROCESS HAZARDS

Some hazards and potential causes of releases for hydrogen cyanide releases directly related to its properties and specific processes were identified in the preceding sections. This section summarizes these, and discusses more general hazards common to any facility producing or using hydrogen cyanide. Hydrogen cyanide releases can originate from many sources including ruptures in process equipment, separated flanges, actuated relief valves or rupture discs, and failed pumps or compressors. In addition, losses may occur through leaks at joints and connections such as flanges, valves, and fittings where failure of gaskets or packing might occur.

The properties of hydrogen cyanide which can promote equipment failure are its ability to self polymerize, its flammability and the violent decomposition reaction that can occur between hydrogen cyanide and acidic solutions.

Potential hydrogen cyanide releases may be in the form of either liquid or vapor. Liquid spills can occur when hydrogen cyanide is released at or below its boiling point of 78.3°F, or when a sudden release of hydrogen cyanide at temperatures above its boiling point results in vapor flashing, thus cooling at least part of the remaining material to below its boiling point. Direct releases of vapor can also occur.

4.1 POTENTIAL CAUSES OF RELEASES

Failures leading to accidental releases may be broadly classified as due to process, equipment, or operational causes. This classification is for convenience only. Causes discussed below are intended to be illustrative, not exhaustive. A more detailed discussion of possible causes of accidental releases is planned in other portions of the prevention reference manual series of which this present manual is a part.

4.1.1 Process Causes

Process causes are related to the fundamentals of process chemistry, control and general operation. Examples of possible process causes of a hydrogen cyanide release include:

- Overheating of cyanide manufacturing reactor resulting in rapid thermal decomposition;

- Loss of flow/composition control where acid stabilizer is added to a hydrogen cyanide stream resulting in excess acid. High acid levels can result in rapid decomposition and overpressure;

- Loss of flow/composition control where acid stabilizer is added to a hydrogen cyanide stream resulting in low acid levels. Low acid levels can result in polymerization-decomposition;

- Loss of flow/composition control where abnormally high levels of hydrogen cyanide is fed to a reactor along with a basic catalyst or reactant. Excess hydrogen cyanide is likely to polymerize-decompose under such conditions;

- Loss of adequate mixing where hydrogen cyanide is fed to a reactor along with a basic catalyst or reactant. Localized high concentrations of hydrogen cyanide can polyerize-decompose;

- Loss of pH control where acetone cyanohydrin is present resulting in the decomposition to acetone and hydrogen cyanide. Such decomposition could result in overpressure and an accidental release;

- Overpressure of any storage or process vessels containing hydrogen cyanide due to over heating resulting in polymerization-decomposition;

- Excess hydrogen cyanide feed leading to overfilling or overpressuring equipment;

- Backflow of alkaline or strongly acidic materials into hydrogen cyanide storage or process vessel resulting in polymerization-decomposition; and

- Catalyst decay in hydrogen cyanide production reaction resulting in overheating of the reactor.

4.1.2 Equipment Causes

Equipment causes of accidental releases result from hardware failure. Some possible causes include:

- Excessive stress due to improper fabrication, construction, or installation;

- Failure of vessels at normal operating conditions due to weakening of equipment from excessive stress, external loadings, or corrosion;

- Mechanical fatigue and shock in any equipment. Mechanical fatigue could result from age, vibration, or stress cycling, caused by pressure cycling, for example. Shock could occur from collisions with moving equipment such as cranes or other equipment in process or storage areas;

- Creep failure in equipment subjected to extreme operational upsets, especially excess temperature. This can occur

in equipment subjected to fire that may have caused damage before being brought under control;

- Failure of any equipment that is exposed to hydrogen cyanide due to stress corrosion cracking, especially equipment subject to vibration or other forms of mechanical stress; and

- All forms of corrosion; specific type will be process and material specific.

4.1.3 Operational Causes

Operational causes of accidental releases are a result of incorrect procedures or human errors (i.e., not following correct procedures). These causes include:

- Overfilled storage vessels;

- Errors in loading and unloading procedures;

- Inadequate maintenance in general, but especially on pressure relief systems and other preventive and protective systems; and

- Lack of inspection and non-destructive testing of vessels and piping to detect corrosion weakening.

SECTION 5
HAZARD PREVENTION AND CONTROL

5.1 GENERAL CONSIDERATIONS

Prevention of accidental releases relies on a combination of technological, administrative, and operational practices. These practices apply to the design, construction, and operation of facilities where hydrogen cyanide is stored and used. Considerations in these areas can be grouped as follows:

- Process design;
- Physical plant design;
- Operating and maintenance practices; and
- Protective systems.

In each of these areas, consideration must be given to specific factors that could lead to a process upset or failure which could directly cause a release of hydrogen cyanide to the environment, or result in an equipment failure which would then cause the release. At a minimum, equipment and procedures should be examined to ensure that they are in accordance with applicable codes, standards, and regulations. In addition, stricter equipment and procedural specifications should be in place if extra protection against a release is considered appropriate.

Most of the large manufacturers of hydrogen cyanide provide detailed assistance as to proper storage and handling practices for their customers that use the chemical. One large company requires all of their customers to

comply with their safety practices and will routinely inspect customer's facilities for compliance. This same company offers an annual seminar on safe storage and handling practices of hydrogen cyanide. This seminar is attended by customers as well as other producers that license technology from the sponsoring company (21). Such practices have contributed significantly toward reducing the risk of an accidental release of hydrogen cyanide.

Release prevention is discussed in the following subsections. More detailed discussions will be found in a manual on control technologies, part of this manual series.

5.2 PROCESS DESIGN

Process design involves the fundamental characteristics of the processes which use hydrogen cyanide. This includes an evaluation of how deviations from expected process design conditions might initiate a series of events that could result in an accidental release. The primary focus is on how the process is controlled in terms of the basic process chemistry, and the variables of flow, pressure, temperature, composition, and quantity. Additional process design issues may include mixing systems, fire protection, and process control instrumentation. Modifications to enhance process integrity may result from review of these factors and would involve changes in quantities of materials, process pressure and temperature conditions, the unit operations, sequence of operations, the process control strategies, and instrumentation used.

Table 5-1 shows the relationship between some specific process design considerations and individual processes described in Section 3 of this manual. This does not mean that other factors should be ignored, nor does it mean that proper attention to just the considerations in the table ensures a safe system. The items listed, and perhaps others, must be properly addressed if a system is to be safe, however.

TABLE 5-1. KEY PROCESS DESIGN CONSIDERATIONS FOR HYDROGEN CYANIDE PROCESSES

Process Design Consideration	Process or Unit Operation
Flow control of hydrogen cyanide feed	All (hydrogen cyanide is almost always used as the limiting reactant).
Mixing	Sodium cyanide reactor, continuous stirred tank methyl methacrylate reactor, all operations where hydrogen cyanide is mixed with alkaline or acidic materials.
Composition monitoring and control (including pH)	Hydrogen cyanide storage vessels, feed to hydrogen cyanide production process. Should be considered for all operations where high concentrations and/or large quantities of hydrogen cyanide are used.
Temperature sensing and heating/cooling media flow control	All operations where high concentrations and/or large quantities of hydrogen cyanide are used.
Adequate pressure relief	Storage tanks, reactors, distillation and stripping columns, heat exchangers.
Level sensing and control	Storage tanks, reboilers and condensers, batch or continuous stirred tank reactors
Corrosion monitoring	All, but especially equipment exposed to hydrogen cyanide and mechanical stress at the same time.

5.3 PHYSICAL PLANT DESIGN

Physical plant design includes equipment, siting and layout, and transfer/transport facilities. Vessels, piping and valves, process machinery, instrumentation, and factors such as location of systems and equipment must all be considered. The following subsections cover various aspects of physical plant design beginning with a discussion of materials of construction. This section is not intended to provide detailed specifications for the design of a facility handling hydrogen cyanide. The discussion is intended to be illustrative, but not comprehensive.

5.3.1 Equipment

Materials of Construction--

The primary concern in selecting the appropriate materials of construction is the prevention of major hydrogen cyanide solution spills and prevention of contamination of the hydrogen cyanide.

Anhydrous hydrogen cyanide is generally not considered corrosive. Under ambient temperatures carbon steel is an acceptable material of construction. As an example, for storage vessels, one distributor recommends ASTM A516 grade 60 steel that has been acid pickled using a 0.5% H_2SO_4 solution for ten to twelve hours (3). However, there are conditions under which hydrogen cyanide will be corrosive to carbon steel. In general carbon steel is only appropriate for ambient storage of hydrogen cyanide.

Elevated temperatures, the presence of an acid stabilizer, and the presence of water will all effect the corrosiveness of a hydrogen cyanide solution. Water solutions of hydrogen cyanide can result in transcrystalline stress- cracking of carbon steels under stress even at room temperature and in dilute solution (2). Under more severe conditions of temperature and pressure, solutions of hydrogen cyanide may also result in stress corrosion cracking of stainless steels and nickel-chromium and nickel-copper alloys

(22). Additionally, water solutions of hydrogen cyanide containing sulfuric acid as a stabilizer severely corrode carbon steel above 100°F and stainless steels above 175°F (2).

Austenitic stainless steels resist corrosion by sulfur dioxide-stabilized hydrogen cyanide and water mixtures at all concentrations and at temperatures up to the atmospheric boiling point. Types 316 and 317 stainless steels have greater corrosion resistance than stainless steels without molybdenum (23). Unstabilized stainless steels should be fully annealed to prevent intergranular attack (23). In higher temperature applications, nickel-chromium and nickel-copper alloys must be used. Care must be taken for correct material selection in these situations, since these materials may also be subject to stress corrosion cracking by hydrogen cyanide.

A number of nonmetallic materials show good resistance to hydrogen cyanide. Table 5-2 shows a list of plastics and elastomers and their relative resistance to chemical attack by aqueous hydrogen cyanide solutions. It is important to realize that the conditions under which these material were tested was limited to pure hydrogen cyanide and water mixtures at the temperature indicated on the chart. The addition of other chemical constituents could effect the corrosion resistance of the material. Higher temperatures may also effect the performance of these materials. In addition, this table says nothing about the physical characteristics of these materials. Although a material may show good chemical resistance it may not have the physical properties necessary for use in chemical equipment. Only materials that show excellent chemical resistance to hydrogen cyanide should be considered for use in a facility that handles the chemical. Actual material selection for a given application should be done in consultation with a vendor having experience with hydrogen cyanide systems.

Vessels--

Most hydrogen cyanide is stored in refrigerated atmospheric storage vessels. Many of the design features for hydrogen cyanide storage tanks

TABLE 5-2. CHEMICAL RESISTANCE OF POLYMERS AND ELASTOMERS TO CHEMICAL ATTACK BY WET HYDROGEN CYANIDE

Material	Resistance to Chemical Attack*
Chlorinated Polyether	Excellent at 250°F
Polyvinylidene Fluoride	Excellent at 275°F
Polyamide	Unacceptable
Polyethylene	Good at 150°F
Polyimides	Good at 150°F
Polyphenylene oxide	Unacceptable
Polyphenyl sulfide	Good at 150°F
Polypropylene	Good at 150°F
Polystyrene	Good at 150°F
Polysulfone	Unacceptable
Polyvinyl chloride (types I & II)	Excellent at 150°F
Chlorinated PVC	Fair at 150°F
Polysulfone	Unacceptable
Vinylidene Chloride	Good at 150°F
Epoxy Resin	Excellent at 150°F
Furan Resin	Excellent at 150°F
Phenolic Resin	Excellent at 150°F
Polyesters	Good at 220°F
Vinyl ester	Fair at 150°F
Natural soft rubber	Good at 150°F
Butadieneacrylonitrile	Unacceptable
Butyl rubber	Good at 150°F
Chloroprene rubber	Excellent at 150°F
Chlorosulfonated polyethylene	Excellent at 150°F
Polysulfide rubber	Excellent at 150°F
Polyurethane elastomer	Excellent at 150°F

* The materials listed may or may not show similar chemical resistance at higher temperatures.

center around the ability of the chemical to experience polymerization - decomposition. Because of this, a number of safety features should be incorporated into the design of any hydrogen cyanide storage tank. A list of these items is presented below:

- Tank cooling system;
- Temperature monitoring with high temperature alarm;
- Tank sampling system;
- Grounding connection;
- Level monitoring with alarm;
- Pressure monitoring with high pressure and vacuum alarm;
- Acid addition system;
- Emergency pressure relief; and
- Clean nitrogen supply for maintaining an inert atmosphere in the tank.

In addition to these features a number of other features should be considered for a hydrogen cyanide storage tank. Examples include:

- Tank vent with vapor condenser, vent discharge to flare, scrubber or equivalent treatment device;
- Second high level alarm;

- Dedicated nitrogen supply (for use with hydrogen cyanide storage only);

- Dike around storage tank; and

- Area monitors that activate deluge system when hydrogen cyanide is detected.

The cyanide polymerization - decomposition reaction is best detected by a rise in tank temperature. The second method of detection is color change. Hydrogen cyanide that has not polymerized has a "straw yellow" appearance. The color will darken as the reaction occurs until it reaches a dark brown; at this point the reaction may be proceeding at a dangerous rate. For these reasons the temperature of a hydrogen cyanide storage tank should be continuously monitored; any increase in temperature should be considered suspect. Samples should be withdrawn periodically from the storage tank to observe physical appearance and to test for acidity and water content. One major distributor recommends that such samples should be withdrawn at least two times per week (3). Others have suggested that sampling be carried out at least every twenty four hours (25).

Cooling of a hydrogen cyanide tank can be accomplished by a recirculation loop with a heat exchanger in the loop or by cooling jackets around the outside of the vessel. Leakage of some varieties of coolant into the hydrogen cyanide storage vessel can promote polymerization. For this reason a recirculation loop may be more appropriate than a jacketed vessel, as it is easier to inspect the integrity of a single heat exchanger than the jacket on an entire vessel. Ammonia should never be used as a refrigerant as it can neutralize the acidic stabilizer in the hydrogen cyanide.

An acid addition tank should be present on storage tanks so that acid can be added to stabilize a hydrogen cyanide tank where polymerization has been detected. The acid should not be added directly to the tank, as localized

high concentrations of acid can result in violent decomposition of the hydrogen cyanide. A system for mixing the acid, either by addition to the recirculation loop or by addition with nitrogen injection should be developed. Usually the acid addition is designed to be manually operated once the polymerization reaction has been detected. However, an automated system to inject acid based on temperature rise could be developed. Usually, however, there is ample time to decide whether acid should be added.

The purity of the nitrogen that is fed to the tank is very important. Contamination brought in with the nitrogen could result in a polymerization reaction. Dryers and filters should be present on all nitrogen supplies. Additionally, extreme care should be taken to assure that no cross contamination can occur between the hydrogen cyanide storage tank and other systems using the same nitrogen supply. The best system in one where the hydrogen cyanide storage tank has a nitrogen supply that is dedicated for use by the hydrogen cyanide storage system only.

When the tank is operated at atmospheric pressure extreme care must be taken to avoid contamination through the vent system. One possible solution to this is to have a vent system that is used only for the hydrogen cyanide storage tank. Another method for reducing the potential for vent contamination would be to continuously feed a small amount of nitrogen into the tank and out the vent. Whenever a vented storage vessel is used it should be equipped with a vacuum alarm, as the presence of a vacuum in the tank will create a reverse flow in the vent and potentially draw air or other forms of contamination into the tank.

Structurally the tank should be constructed according to a code quality design. One vendor recommends that atmospheric pressure storage vessels be designed for 25 psig minimum, with a corrosion allowance of at least 1/16 inch. The tank should be able to withstand vacuum. The tank should have no bottom outlets. Dip pipes should be of a large enough diameter to prevent high velocity impact with the bottom of the tank; such impact can result in

erosion-corrosion (3). This same vendor provides additional specifications for tank design.

Vessels such as reactors and heat exchangers that handle hydrogen cyanide must be designed with many of the same considerations in mind that were listed above for storage vessels. Protection must be provided against the potential for polymerization - decomposition. The specific precautions will depend on the process involved. Release prevention considerations for all vessels include prevention of overpressure, overfilling, overheating, and corrosion.

Many of the processes that use hydrogen cyanide react the chemical with an alkaline material at elevated temperatures. In these situations precautions to reduce the risk of polymerization will include adequate, mixing, flow and composition control and temperature control. Therefore reaction vessels of this type must be designed with adequate monitoring and backup of one or all of these parameters.

All vessels that handle hydrogen cyanide must be equipped with adequate overpressure protection. Where possible the discharge from these overpressure protection devices should be sent to a protection system such as a scrubber or flare. Care must be taken to prevent material from other process units from contaminating the hydrogen cyanide system through the vent system. Overpressure protection systems will be discussed in a latter portion of this manual.

Prevention of overfilling can be accomplished using level sensing devices, pressure relief devices, and adequately trained personnel. Redundant level sensing devices are often appropriate where hydrogen cyanide is used. Where a pressure relief device is used as overflow protection, the discharge from the valve should go to a catch tank. Such a valve should not be used for overpressure protection, as a valve that is sized to release vapor in the event of an overpressure will be grossly undersized if it must release liquid in the event of an overpressure.

Because of its flammability, the contents of hydrogen cyanide vessels should be kept under an inert atmosphere unless process requirements dictate alternate conditions. This can be done using nitrogen. The inert gas that is used for such purposes should be filtered and dried. Precautions must be taken to prevent cross contamination through the nitrogen system, and in some cases it may be preferable to have a separate nitrogen supply for the hydrogen cyanide system.

Piping--

The characteristics of hydrogen cyanide that are most important when designing piping systems are:

- The high acute toxicity of the chemical;
- Its ability to cause stress corrosion cracking; and
- Its ability to polymerize.

The high toxicity of hydrogen cyanide is of concern because even small leaks in a piping system can be dangerous to operating personnel. Hydrogen cyanide piping should be constructed with welded connections that are fully radiographed. The use of flanges should be minimized and threaded fittings should never be used.

Valves should have a leak-tight gland or be leakproof such as a diaphragm or bellow-sealed valve. The valve stem seals should be externally adjustable to stop stem leakage, and the stem should not be removable while the valve is in service. Excess flow valves should be considered at the inlet and outlet of hydrogen cyanide vessels.

For maintenance and emergencies, it is often useful to be able to isolate vessels and other hydrogen cyanide process equipment. Remotely operated emergency isolation valves should be considered wherever a large release could prevent access to an isolation valve. In some cases a single valve is

insufficient to ensure complete isolation, and the use of slip plates or a double block and bleed arrangement may be necessary. Because of the potential for releasing trapped hydrogen cyanide, proper training is essential to ensure safe operation of these isolation techniques.

Several precautions must be taken in light of ability of hydrogen cyanide to cause stress corrosion cracking. Piping, valves and fittings should all be constructed of 316 stainless steel. Flange nuts and bolts should also be constructed of a material that is resistant to hydrogen cyanide attack as fugitive leaks can attack these as well (3). Gaskets should be 316 stainless steel-graphite spiral-wound or similar type, as these provide more sure leak protection than asbestos composites. These specifications may not be sufficient for high temperature applications. In such cases hydrogen cyanide resistant alloys such as inconel may be required.

Because of stress corrosion, piping equipment that is subject to vibration, such as near a pump, are of particular concern. Piping should be adequately supported, as stress and vibration over a long period of time will significantly contribute to the potential for stress cracking. Tees and other similar fittings should be forged instead of welded as welds are particularly susceptible to stress cracking.

Polymerization of hydrogen cyanide within a piping system will result in restricted or blocked flow and can result in an overpressured line; both of which could contribute to an accidental release. Dead ends or rarely used sections of piping should be avoided as polymerization can occur where stagnant hydrogen cyanide is present. Piping should be well insulated from exposure to heat. Even warming by the sun on uninsulated piping can contribute to polymerization. Pipe runs should be pitched so that they drain when flow is stopped. Sections of pipe where liquid hydrogen cyanide could be trapped by valves should be equipped with overpressure protection. Ball and plug valves should be designed so that excess pressure in the body will relieve spontaneously toward the high pressure side. This is accomplished by

providing a relief hole in the valve body (or the ball or plug) which bypasses the upstream seat. Modified valves such as these must indicate the flow direction on the valve body.

Process Machinery --

Pumps-- Many of the concerns and considerations for hydrogen cyanide piping and valves also apply to pumps. To assure that a given pump is suitable for hydrogen cyanide service, the system designer should obtain information from the pump manufacturer certifying that the pump will perform properly in this application.

Wetted parts should be made of 316 stainless steel. Mechanical seals are preferred over packing for better leak protection. Double mechanical seals with a barrier fluid provide even better leak protection. In some situations the potential for a leak may be so undesirable that rotating shaft seals are not appropriate. Pumps that do not have external rotating shaft seals are, canned-motor, vertical extended-spindle submersible, magnetically coupled, and diaphragm pumps (26).

Pumps should be equipped with overpressure protection. Positive displacement pumps should have pressure relief that vents to a safe location. Alternately, positive displacement pumps can be equipped with pump-around loops. However, because a pump-around loop increases the complexity of the system, and the number of valves and fittings, it may increase the risk of a release. By bypassing the pump, the pump-round loop also eliminates the positive displacement pump as a back flow protection device.

Deadheading a centrifugal pump can also result in a release by overheating the hydrogen cyanide trapped within the pump. This can result in the initiation of a polymerization - decomposition reaction within the pump. The pump seal is very likely to fail under these conditions. One method of reducing the risk associated with such an event is to install a flammable gas detector just on the outside of the mechanical seal. The detector could be

connected to a deluge system that could be activated in the event of even a small release from the pump seal.

Pumps handling cyanide solutions should be located within a curbed or diked area. Remotely operated shutoff valves to stop the flow to a pump should be considered wherever a release of hydrogen cyanide could prevent access to the pump.

Pressure Relief Devices--In most cases, emergency pressure relief should be vented to a treatment device such as a flare or scrubber. In some cases, venting can be done to a catch tank although sizing the tank in such a situation may be difficult. A pressure relief valve mounted above a rupture disk is suitable for hydrogen cyanide overpressure protection. The line below the relief valve should be continually purged with nitrogen so as to prevent plugging the relief line by the vapor phase formation of hydrogen cyanide polymer. Two valves with rupture disks in parallel are recommended so that one device can be open to the tank while the other is in service. In such situations, it is important to interlock the valves that isolate the pressure relief valves from the process so that only one relief valve can be isolated from the process at one time.

A relief valve is sized so that in the event of a polymerization - decomposition reaction, the temperature of the tank contents will be controlled by the boil off rate of hydrogen cyanide. Thus, by controlling the temperature, the rate of polymerization will be controlled at a manageable level. One vendor suggests that relief devices on hydrogen cyanide storage tanks be set at 5 psig. This will allow for sufficient heat removal in the event of a polymerization - decomposition reaction (3). It is difficult to get a device that can accurately release at this low of a pressure.

In some situations, two-phase flow through the relief valve may be possible and this must be considered. A thorough understanding of the kinetics of the hydrogen cyanide polymerization - decomposition reaction is

important for sizing the relief device. Vendors of hydrogen cyanide have this kinetic data and will provide assistance for sizing overpressure protection. One vendor has combined kinetic data with the data developed by the Design Institute for Emergency Relief Systems, (DIERS) on two-phase releases to size relief valves for their customers (27).

Where possible, pressure relief vent and treatment systems on hydrogen cyanide storage and handling equipment should not be connected to any other pieces of process equipment. This will help prevent cross-contamination between systems. A flame arrester may be used in the vent line. However, such a device should be cleaned frequently to prevent plugging by hydrogen cyanide polymer.

Instrumentation--Instrumentation should be constructed of materials that are compatible with hydrogen cyanide service. In many cases wetted materials can be made of 316 SS or of an elastomer of plastic with hydrogen cyanide resistance. With the exception of high temperature operations, hydrogen cyanide is not a severe environment for most instrumentation. However, one concern when using instrumentation with hydrogen cyanide is the potential for vapor phase polymerization. Such polymer could plug measuring wells or foul sensors and isolate the instrument from the actual process environment. Example solutions for this are the use of redundant instruments, the use of instruments that may be cleaned while in service or the use of nitrogen purge streams to keep the sensing element free from hydrogen cyanide polymer formation (a nitrogen purge should be used with caution, as it could adversely affect the accuracy of some instruments).

5.3.2 Plant Siting and Layout

The siting and layout of a particular facility using hydrogen cyanide requires careful consideration of numerous factors. These include: other processes in the area, the proximity of population centers, prevailing winds, local terrain, and potential natural external effects such as flooding. The

rest of this subsection describes general considerations which might apply to siting and layout of facilities that handle hydrogen cyanide.

Siting of facilities or individual equipment items should be done in a manner that reduces personnel exposure, both plant and public, in the event of a release. Since there are also other siting considerations, there may be trade-offs between this requirement and others in a process, some directly related to safety. Siting should provide ready ingress or egress in the event of an emergency and yet also take advantage of barriers, either man-made or natural which could reduce the consequences of releases.

Layout refers to the placement and arrangement of equipment in the process facility. General layout considerations include:

- Inventories of hydrogen cyanide should be kept away from sources of fire or explosion hazard;
- Vehicular traffic should not go too near hydrogen cyanide process or storage areas if this can be avoided;
- Where such traffic is necessary, precautions should be taken to reduce the chances for vehicular collisions with equipment, especially pipe racks carrying hydrogen cyanide across or next to roadways;
- Hydrogen cyanide piping preferably should not be located adjacent to other piping which is under high pressure or temperature;
- Storage facilities should be segregated from the main process unless the hazards of pipe transport are felt to outweigh the hazard of the storage tank for site-specific cases; and

- Storage should also be situated away from control rooms, offices, utilities, storage, and laboratory areas.

Various techniques are available for formally assessing a plant layout and should be considered when planning high hazard facilities handling hydrogen cyanide (28). These techniques provide for a systematic evaluation of key siting and layout factors.

Because heat increases the tendency of hydrogen cyanide to undergo polymerization - decomposition, measures should be taken to situate piping, storage vessels, and other hydrogen cyanide equipment in such a way as to minimize their exposure to heat. Hot process piping, equipment, steam lines, and other sources of direct or radiant heat should be avoided.

In the event of an emergency, there should be multiple means of access to the facility for emergency vehicles and crews. Storage vessel shut off valves should be readily accessible. Containment for liquid storage tanks can be provided by diking. Flammable gas detectors and adequate fire protection must be provided for all portions of the process as hydrogen cyanide is flammable when mixed with air.

5.3.3 Transfer and Transport Facilities

Transfer and transport facilities where rail tankers are loaded and unloaded are potential accident areas because of vehicle movement and the intermittent nature of the operations. Therefore, special attention should be given to the design of these facilities.

Rail car unloading and loading facilities should be equipped with the following safety and release prevention features;

- Grounding connections for the car and rails;

- A car "come-along" for accurate positioning, wheel chocks, and derailers for runaway cars;

- Warning signs and lights to identify the area and restrict access during the loading or unloading;

- High pressure piping and hoses, connectors on hose ends that are unique for hydrogen cyanide service and that prevent accidental attachment of the vapor hose to the liquid line on the car, or the liquid receiving line to the vapor line of the car;

- Rail car temperature monitor and alarm;

- Deluge system for the rail car area, or at a minimum sufficient fire hoses or monitors to act as a deluge in the even of a spill; and

- Some type of drainage control system that prevents runoff from a spill from traveling into unwanted areas.

Usually a tank car will be unloaded by applying nitrogen pressure to the vapor space, thereby pushing the liquid out through the rail car dip tube. As mentioned previously, nitrogen used for hydrogen cyanide service must be free of any contamination. Additionally, back flow protection should also be provided in the nitrogen line.

In some situations, unloading a tank car will require several hours. When this is the case, the tank car should be treated as a storage tank with periodic samples withdrawn from the car to test for the formation of polymer. Whenever tank cars are loaded or unloaded, written operating procedures should be developed and enforced.

5.4 PROTECTION TECHNOLOGIES

This subsection describes three types of protection technologies for containment, treatment and neutralization. These are:

- Enclosures;
- Flares; and
- Scrubbers.

A presentation of more detailed information on these systems is planned in other portions of the prevention reference manual series.

5.4.1 Enclosures

Enclosures refer to containment structures which capture any hydrogen cyanide spilled or vented from storage or process equipment, thereby preventing immediate discharge of the chemical to the environment. The enclosures contain the spilled liquid until it can be transferred to other containment, discharged at a controlled rate which would not be injurious to people or the environment, or transferred at a controlled rate to scrubbers for neutralization or a flare or incinerator for destruction.

The use of specially designed enclosures for either hydrogen cyanide storage or process equipment does not appear to be widely practiced. The location of toxic operations in the open air has been mentioned favorably in the literature, along with the opposing idea that sometimes enclosure may be appropriate (29). The desirability of an enclosure depends partly on the frequency with which personnel must be involved with the equipment. A common design rationale for not having an enclosure where toxic materials are used is to prevent the accumulation of toxic concentrations of a chemical within a work area. However, if the issue is protecting the community from accidental releases, then total enclosure may be appropriate. Enclosures should be equipped with continuous monitoring equipment and alarms. Alarms should sound

whenever lethal or flammable concentrations are detected. Enclosures for hydrogen cyanide should be equipped with adequate fire protection.

Care must be taken when an enclosure is built around pressurized equipment. It would not be practical to design an enclosure to withstand the pressures associated with the sudden failure of a pressurized vessel. An enclosure would probably fail as a result of the pressure created from such a release and could create an additional hazard. In these situations, it may be determined that an enclosure is not appropriate. If an enclosure is built around pressurized equipment then it should be equipped with some type of explosion protection, such as rupture plates that are designed to fail before the entire structure fails.

The type of containment structures that could be suitable for hydrogen cyanide are concrete block or concrete sheet buildings, or bunkers or corrugated metal buildings. An enclosure would have a ventilation system designed to draw in air when the building is vented to a scrubber or flare. The bottom section of a building used for stationary storage containers should be liquid tight to retain any liquid hydrogen cyanide that might be spilled. Buildings around rail car unloading stations do not lend themselves well to effective liquid containment. However, containment could be accomplished if the floor of the building were excavated several feet below the track level while the tracks are supported at grade in the center.

While the use of enclosures for secondary containment of hydrogen cyanide spills or releases is not known to be widely used, it can be considered as a possible protection technology for areas near especially sensitive receptors.

5.4.2 Flares

Flares are used in the chemical process industries to dispose of intermittent or emergency emissions of hydrogen cyanide waste gases. The flare

burns the waste gases, forming carbon dioxide and nitrogen oxides. Flares are capable of handling larger flow variations than are process combustion devices such as boilers.

The two common styles are elevated and enclosed ground flares. The height of an elevated flare (sometimes several hundred feet) is determined by safety considerations for the surrounding areas because of the high temperatures and heat flux at maximum gas rates. Enclosed ground flares consist of stages of multiple burner assemblies surrounded by refractory walls and acoustical insulation. They are generally used for small to medium flow rate applications. The elevated flare is used for larger gas flows. Often, an enclosed ground flare will be used in conjunction with an elevated flare for economical operation.

A flare system may collect gases from just one source or more often it may be used to treat gases from multiple sources within a process. Because most flare systems collect gases from a variety of sources within a plant, gas compositions and flow rates vary. Many units include venting steps to the flare system during processing. Overpressurization can also cause relief valves to vent gases to the flare system. Depending on the size of the flare system, accidental releases may constitute a large or small fraction of the instantaneous gas flow. The flow rate under an emergency release from a vessel could constitute a significant or negligible portion of the total flow rate to a flare. This would depend on the time interval over which the release occurred and the flow rate of other materials going to the flare at the same time. Flare designs range up to and above 2 million pounds per hour.

Several design characteristics of flare systems are important when considering their use as protection against accidental chemical releases. The design of flares is dictated by the desire to:

- Operate the flare safely over a wide range of gas flow-rates; and

- Have acceptable emissions of radiant heat, toxic and flammable materials, and noise.

A fundamental flare design variable is exit velocity. At maximum flow, the flame should not leave the burner tip or be blown out. This is achieved by limiting the exit velocity. A criterion has been recommended by the EPA to ensure 98 percent destruction efficiency of flared chemicals using a steam assisted flare (30). The addition of an accidental release discharge to an existing flare must not cause this maximum flow to be exceeded.

Flares can be useful protection against accidental releases of hydrogen cyanide. However, because of potentially dangerous secondary hazards, their use requires a thorough analysis for each specific application.

There are two possible ways a flare system can be used to protect against accidental releases. The first is to use an existing flare system. The second is to use a dedicated "emergency" system. In essence, a flare system is a pipe transporting flammable gases to a flame at the exit. As long as the flame remains at the end of the pipe, the system operates safely. The flame can enter the pipe if air or oxygen is present above a certain concentration in the fuel. In a dedicated flare system, the entire collection network would have to be continually purged to prevent the risk of an explosion when an accidental release occurred.

Since the flare collection system operates under a positive pressure (above atmospheric), release rates from an emergency relief valve will be less than the same discharge to the atmosphere. In some instances, it is conceivable that the slight delay in reducing the pressure in a vessel may cause tank damage. This may be especially important when rupture disks blow. A sudden overpressurization of the flare collection system due to a massive accidental release could damage the pipes or potentially affect the venting of other process units. Table 5-3 summarizes the factors that need to be considered to prevent accidental chemical releases when using a flare system.

TABLE 5-3. IMPORTANT CONSIDERATIONS FOR USING FLARES TO PREVENT ACCIDENTAL CHEMICAL RELEASES

- Maximum flow rate - will it cause a flame blowout? Will it cause mechanical damage due to vibration?
- Possibility of air, oxygen, or other oxidant entering system?
- Is gas combustible - will it smother the flare?
- Will any reactions occur in collection system?
- Can liquids enter the collection system?
- Will liquids flash and freeze, or overload knockout drum?
- Is back pressure of collection system dangerous to releasing vessel?
- Is releasing vessel gas pressure or temperature dangerous to collection system?
- Will acids or salts enter collection system?
- Will release go to an enclosed ground or elevated flare?
- If toxic is not destroyed, what are the impacts on surrounding community?

The rationale for using flares to protect against accidental chemical releases is that flaring reduces the effects of an atmospheric emission from a process vessel. As long as the integrity of the flare system is not compromised, some lessening of the overall environmental impact would be expected. It is difficult to estimate the destruction and removal efficiency (DRE) of flares because of the many variables associated with their operation. Numerous studies have been conducted to determine the operational performance of flares. EPA has published a set of flare requirements to ensure 98 percent or greater destruction of the gases (30). In an emergency condition, however, these conditions might not be met. In a screening study conducted by EPA, a 100 ppm hydrogen cyanide stream was only 85 percent controlled (31).

Because of the variable flow capacity, high flame temperature, capability for handling a high gas velocity, and usual remote location, using a flare to prevent accidental chemical releases of hydrogen cyanide can be an effective technique. Small or isolated vessels in a process which does not require normal venting of a flammable gas, and that employ relief valves and rupture disks which may have never been used, are examples of sources that can be connected to a flare system to prevent accidental releases.

5.4.3 Scrubbers

Scrubbers are a traditional method for absorbing toxic gases from process streams. These devices can be used to control hydrogen cyanide releases from vents and pressure relief discharges from storage equipment, process equipment, or secondary containment enclosures.

Hydrogen cyanide discharges could be contacted with an aqueous scrubbing medium in any of several types of scrubbing devices. An alkaline solution is recommended to achieve effective absorption because absorption rates with water alone would require high liquid-to-gas ratios. However, water scrubbing could be used in a make-shift scrubber in an emergency if an alkaline solution

was not available. Typical alkaline solutions for an emergency scrubber would be calcium hydroxide derived from slaked lime or sodium hydroxide.

Examples of scrubber types that might be appropriate include spray towers, packed bed scrubbers, and venturis. Other types of special designs might be suitable. Whichever type of scrubber is selected, a key consideration for emergency systems is the design flow rate to be used. A conservative design would use the maximum rate that would be expected from an emergency.

Whatever type of scrubber is selected, a complete system would include the scrubber itself, a liquid feed system, and reagent makeup equipment. If such a system is used as protection against emergency releases, consideration must be given to how it would be activated in time to respond to an emergency load. One approach used in some process facilities is to maintain a continuous circulation of scrubbing liquor through the system. For many facilities this would not be practical, and the scrubber system might be tied into a trip system to turn it on when it is needed. However, with this system, a quantity of hydrogen cyanide would be released prior to actuation of the scrubber (i.e., starting up a blower and turning on the flow of liquid).

The scrubber system must be designed so as not to present excessive resistance to the flow of an emergency discharge. The pressure drop should be only a small fraction of the total pressure drop through the emergency discharge system. In general, at the liquid-to-gas ratios required for effective scrubbing, spray towers have the lowest, and venturis the highest pressure drops. While packed beds may have intermediate pressure drops at proper liquid-to-gas ratios, excessive ratios or plugging can increase the pressure drop substantially. However, packed beds have higher removal efficiencies than spray towers or venturis.

In addition, the scrubber system must be designed to handle the "shock wave" generated during the initial stages of the release. This is particularly important for packed bed scrubbers since there is a maximum pressure with which the gas can enter the packed section without damaging the scrubber

internals. Design of emergency scrubbers can follow standard techniques discussed in the literature, carefully taking into account the additional considerations just discussed.

Another approach is the drowning tank, where the hydrogen cyanide vent is routed to the bottom of a large tank of uncirculating caustic. The drowning tank does not have the high contact efficiency of the other scrubber types. However, it can provide substantial capacity on demand as long as the back pressure of the hydrostatic head does not create a secondary hazard, by impeding an overpressure relief discharge, for example.

5.5 MITIGATION TECHNOLOGIES

If, in spite of all precautions, a large release of hydrogen cyanide were to occur, the first priority would be to rescue workers in the immediate vicinity of the accident and evacuate persons from downwind areas. The source of the release should be determined, and the leak should be stopped, if this is possible. The next primary concern is to reduce the consequences of the released chemical on the plant and the surrounding community. Reducing the consequences of an accidental release of a hazardous chemical is referred to as mitigation. Mitigation technologies include such measures as physical barriers, water sprays and fogs, and foams where applicable. The purpose of a mitigation technique is to divert, limit, or disperse the chemical that has been spilled or released to the atmosphere in order to reduce the atmospheric concentration and the area affected by the chemical. The mitigation technology chosen for a particular chemical depends on the specific properties of the chemical including its flammability, toxicity, reactivity, and those properties which determine its dispersion characteristics in the atmosphere.

If a release occurs from a refrigerated, liquid hydrogen cyanide storage tank, the spilled liquid would heat up to ambient temperature. If the ambient temperature is above the boiling point of hydrogen cyanide (78.3°F), then heat transfer from the air and ground would result in rapid vaporization of the released liquid. If the ambient temperature is below the boiling point of the

hydrogen cyanide then vaporization would be slower but a vapor cloud is still likely to form. It is therefore desirable to minimize the area available for heat transfer to a liquid spill which in turn will minimize the rate of evaporation. Mitigation technologies which are used to reduce the rate of evaporation of a released liquid include secondary containment systems such as impounding basins and dikes.

A post-release mitigation effort requires that the source of the release be accessible to trained plant personnel. Therefore, the availability of adequate personnel protection is essential. Personnel protection will typically include such items as portable breathing air and chemically resistant protective clothing.

5.5.1 Secondary Containment Systems

Specific types of secondary containment systems include excavated basins, natural basins, earth, steel, or concrete dikes, and high impounding walls. The type of containment system best suited for a particular storage tank or process unit will depend on the risk associated with an accidental release from that location. The inventory of hydrogen cyanide and its proximity to other portions of the plant and to the community should be considered when selecting a secondary containment system. The secondary containment system should have the ability to contain spills with a minimum of damage to the facility and its surroundings and with minimum potential for escalation of the event.

Secondary containment systems for hydrogen cyanide storage facilities commonly consist of one of the following:

- An adequate drainage system underlying the storage vessels which terminates in an impounding basin having a capacity as large as the largest tank served; and

- A diked area, with a capacity as large as the largest tank served.

These measures are designed to prevent the accidental discharge of liquid hydrogen cyanide from spreading to uncontrolled areas.

The most common type of containment system is a low wall dike surrounding one or more storage tanks. Generally, for hydrogen cyanide, no more than one tank is enclosed within a diked area to reduce risk. Dike heights usually range from three to twelve feet depending on the area available to achieve the required volumetric capacity. The dike walls should be liquid tight and able to withstand the hydrostatic pressure and temperature of a spill. Low-wall dikes may be constructed of steel, or concrete. Earthen dikes should not be used to contain hydrogen cyanide spills, as the high acute toxicity of the chemical requires a high degree of certainty that the containment surface is impermeable to the spill. Piping should be routed over dike walls, and penetrations through the walls should be avoided if possible. Vapor fences may be situated on top of the dikes to provide additional vapor containment. If there is more than one tank in the diked area, the tanks should be situated on beams above the maximum liquid level attainable in the impoundment.

A low-wall dike can effectively contain the liquid portion of an accidental release and keep the liquid from entering uncontrolled areas. By preventing the liquid from spreading, the low-wall dike can reduce the surface area of the spill. Reducing the surface area will reduce the rate of evaporation. The low-wall dike will partially protect the spill from wind; this can reduce the rate of evaporation. A dike with a vapor fence will provide extra protection from wind and will be even more effective at reducing the rate of evaporation.

A low-wall dike will not reduce the impact of a gaseous hydrogen cyanide release. If materials that would react violently with hydrogen cyanide are stored within the same diked area then the dike will increase the potential

for mixing the materials in the event of a simultaneous leak. A dike also limits access to the tank during a spill.

A covered, remote impounding basin is well suited to storage systems where a relatively large site is available. The flow from the hydrogen cyanide spill is directed to the basin by dikes and channels under the storage tanks which are designed to minimize contact of the liquid with other tanks and surrounding facilities. Because of the high vapor pressure of hydrogen cyanide and the high acute toxicity, the trenches that lead to the remote impounding basin as well as the basin itself should be covered to reduce the rate of evaporation. Additionally, the impounding basin should be located very near the tank area to minimize the amount of hydrogen cyanide that evaporates as it travels to the basin. The impounding basin could be filled with water to instantly dilute the liquid hydrogen cyanide as it flows into the basin.

This type of system has several advantages. The spilled liquid is removed from the immediate tank area. This allows access to the tank during the spill and reduces the probability that the spilled liquid will damage the tank, piping, electrical equipment, pumps or other equipment. In addition, the covered impoundment will reduce the rate of evaporation from the spill by protecting the spill from wind or heating from sunlight.

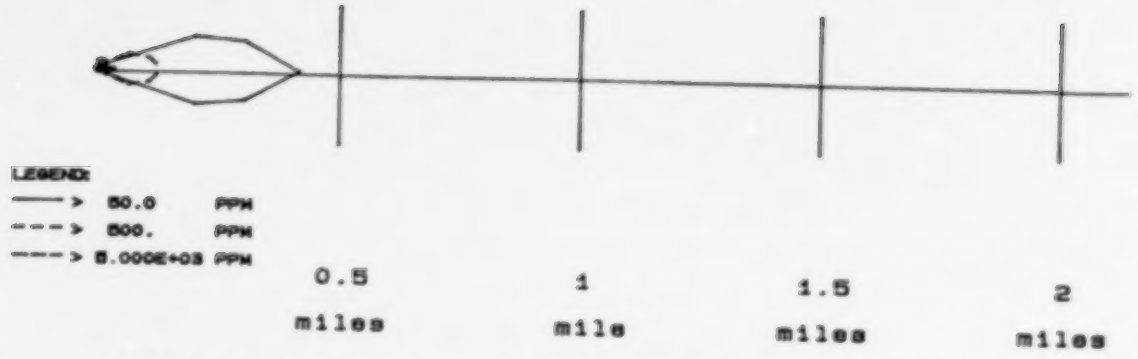
High-wall impoundments may be a good secondary containment choice for selected systems. Circumstances which may warrant their use include limited storage site area, the need to minimize vapor generation rates, and/or the tank must be protected from external hazards. Maximum vapor generation rates will generally be lower for a high wall impoundment than for low wall dikes or remote impoundments because of the reduced surface area exposed to the atmosphere. These rates can be further reduced with the use of insulation on the wall and floor in the annular space. High impounding walls may be constructed of low-temperature steel, reinforced concrete, or prestressed concrete. A weather shield may be provided between the tank and wall with the annular space remaining open to the atmosphere. The available area

surrounding the storage tank will dictate the minimum height of the wall. For high wall impoundments, the walls may be designed with a volumetric capacity greater than that of the tank to provide vapor containment. Increasing the height of the wall also raises the elevation of any released vapor.

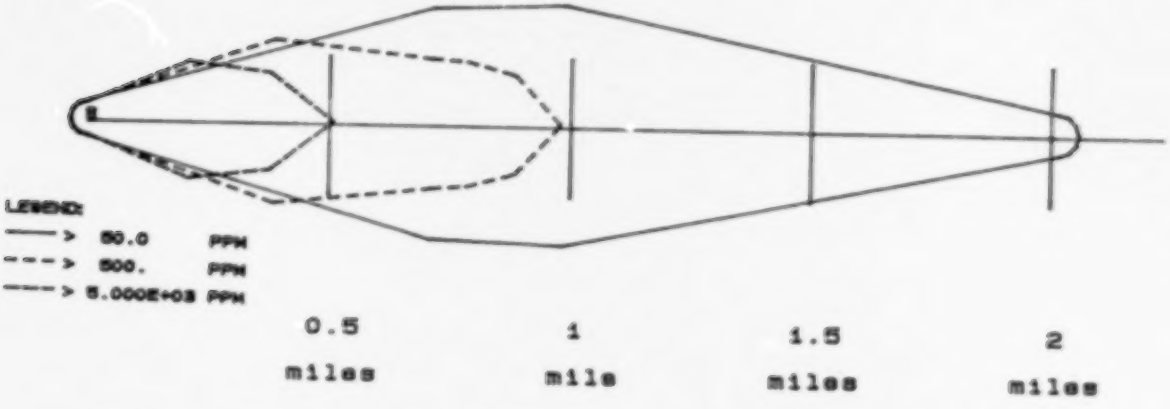
One disadvantage of these dikes is that the high walls around a tank may hinder routine external observation. Furthermore, the closer the wall is to the tank, the more difficult it becomes to access the tank for inspection and maintenance. As with low wall dikes, piping should be routed over the wall if possible. The closeness of the wall to the tank may necessitate placement of the pump outside of the wall, in which case the outlet (suction) line will have to pass through the wall. In such a situation, a low dike encompassing the pipe penetration and pump may be provided, or a low dike may be placed around the entire wall.

An example of the effect of diking as predicted by a vapor dispersion model is shown in Figure 5-1 (32). This figure shows hydrogen cyanide vapor clouds at the time when the farthest distance away from the source is exposed to concentrations above the IDLH. With diking, the model predicts that downwind distances up to 720 feet from the source of the release could be exposed to concentrations above the IDLH. Three minutes are required for the vapors to reach the maximum downwind distance. Without diking, the model predicts that downwind distances up to 2,600 feet from the source could be exposed to concentrations above the IDLH. Thirteen minutes are required for the vapors to reach this distance.

One further type of secondary containment system is one which is structurally integrated with the primary system and forms a vapor-tight enclosure around the primary container. Many types of arrangements are possible. A double-walled tank is an example of such an enclosure. These systems may be considered where protection of the primary container and containment of vapor for events not involving foundation or wall penetration failure are of greatest concern. Drawbacks of an integrated system are the greater complexity of



Release from a tank surrounded by a 25 ft. diameter dike.
Elapsed time: 3 minutes



Release from a tank with no dike.
Elapsed time: 13 minutes

Common Release Conditions:

Storage Temperature = 40°F
Storage Pressure = 14.7 psia
Ambient Temperature = 85°F
Wind Speed = 10 mph
Atmospheric Stability Class = C
Quantity Releases = 5,000 gallons through a 2-inch hole

Figure 5-1. Computer model simulation showing the effect of diking on the vapor cloud generated from a release of refrigerated hydrogen cyanide.

the structure, the difficulty of access to certain components, and the fact that complete vapor containment cannot be guaranteed for all potential events.

Provision should be made for drainage of rainwater from diked areas. This will involve the use of sumps and separate drainage pumps, since direct drainage to storm water sewers would presumably allow any spilled hydrogen cyanide to follow the same route. Alternately, a sloped rain hood may be used over the diked area which could also serve to direct the rising vapors to a single release point (33). The ground within the enclosure should be graded to cause the spilled liquid to accumulate at one side or in one corner. This will help to minimize the area of ground to which the liquid is exposed and from which it may gain heat. In areas where it is critical to minimize vapor generation, surface insulation may be used in the diked area to further reduce heat transfer from the environment to the spilled liquid. The floor of an impoundment should be sealed with clay or concrete to prevent the hydrogen cyanide from seeping into the ground.

5.5.2 Flotation Devices and Foams

Other possible means of reducing the surface area of spilled hydrogen cyanide include placing impermeable flotation devices on the surface or applying water-based foams. Placing an impermeable flotation device over a spilled chemical is a direct approach for containing toxic vapors with nearly 100 percent efficiency. However, being able to use such devices requires acquisition in advance of a spill and storage until needed, and in all but small spills deployment may be difficult. The additional material and dispersal equipment costs are a major deterrent to their use.

The use of foams in vapor hazard control has been demonstrated for a broad range of volatile chemicals. Unfortunately, it is difficult to accurately quantify the benefits of foam systems, because the effects will vary as a function of the chemical spilled, foam type, spill size, and atmospheric conditions. With regard to liquefied gases, it has been found that with some

materials, foams have a net positive effect, but with others, foams may exaggerate the hazard.

One approach to a hydrogen cyanide spill is dilution with water. Deluging a spill with water will dilute the spill and reduce the vapor generation rate. A water-based foam provides an alternative means of diluting the hydrogen cyanide. When a foam cover is first applied, an increase in the boil-off rate is generally observed which would cause a short-term increase in the downwind hydrogen cyanide concentration. The initial foam cover may be destroyed by violent boiling, in which case a second application is necessary. Once a continuous layer is formed, a net positive effect will be achieved in the downwind area. The reduction in downwind concentration is a result of both increased dilution with air, because of a reduced vaporization rate, and the increased buoyancy of the vapor cloud. This latter effect is a result of the vapor being warmed as it rises through the blanket by heat transfer from the foam and by the heat of solution of hydrogen cyanide in water; the warmed vapor cloud will have greater buoyancy and will disperse in an upward direction more rapidly.

The extent of the downwind reduction in concentration will depend on the type of foam used. Regardless of the type of foam used, the slower the drainage rate of the foam, the better its performance will be. A slow-draining foam will spread more evenly, show more resistance to temperature and pH effects, and collapse more slowly. The initial cost for a slow-draining foam may be higher than for other foams, but a cost effective system will be realized in superior performance.

Even if the vaporization rate of hydrogen cyanide is substantially reduced within a short time after a spill, a vapor cloud will still be formed which poses a serious threat downwind. Dispersion and/or removal of the hydrogen cyanide vapor in the atmosphere is the subject of the following section.

5.5.3 Mitigation Techniques for Hydrogen Cyanide Vapor

The extent to which the escaped hydrogen cyanide vapor can be removed or dispersed in a timely manner will be a function of the quantity of vapor released, the ambient conditions, and the physical characteristics of the vapor cloud. The behavior and characteristics of the hydrogen cyanide cloud will be dependent on a number of factors. These include the physical state of the hydrogen cyanide before its release, the location of the release, and the atmospheric and environmental conditions. Many possibilities exist concerning the shape and motion of the vapor cloud, and a number of predictive models of dispersion have been developed. Large accidental releases of hydrogen cyanide may result in the formation of hydrogen cyanide-air mixtures which are denser than the surrounding atmosphere. This type of vapor cloud is especially hazardous, because it will spread laterally and remain close to the ground.

One means of dispersing as well as removing toxic vapor from the air is with the use of water sprays or fogs. However, dilution of hydrogen cyanide with water results in the formation of highly toxic hydrocyanic acid which presents a health hazard to plant personnel.

The spray medium is typically applied to the vapor cloud by means of hand-held hoses and/or stationary water-spray barriers. Important factors relating to the effectiveness of spray systems are the distance of the nozzles from the point of release, the spray pattern, nozzle flow rate, pressure, and nozzle rotation.

Several techniques have also been developed to effectively disperse toxic vapor resulting from major leaks in piping and equipment. One such technique has been developed by Beresford (34). Although such a system has not been used for the mitigation of hydrogen cyanide vapor, they have been effectively used for other toxic chemicals of similar nature (34). Such techniques are not applicable to catastrophic failures of equipment, however.

The method consists of coarse water sprays discharging upwards from flat fan sprays and wide-angled spray monitors arranged so that a vent or chimney effect is created to completely surround the toxic vapor. Results have shown that the high velocity water droplets induce large volumes of air at ground level to move upward as the water discharges upwards (34). The air is caused to move upwards through the chimney formed by the sprays. As the air moves over the ground, the heavier than air toxic gas is diluted and pushed up and out of the top of the chimney where it disperses safely. Design details are presented in Beresford (34). Both types of spray methods are incorporated into the design since the flat-fan sprays effectively stop the lateral spread of vapor and the monitors provide the required air movement for dilution and dispersal.

Another means of dispersing a vapor cloud is with the use of large fans or blowers which would direct the vapor away from populated or other sensitive areas (35). However, this method would only be feasible in very calm weather and in sheltered areas; it would not be effective in any wind and difficult to control if the release occupies a large open area. A large, mechanical blower would also be required which lowers the reliability of this mitigation technique compared to water fogs and sprays.

In general, techniques used to disperse or control vapor emissions should emphasize simplicity and reliability. In addition to the mitigation techniques discussed above, physical barriers such as buildings and rows of trees will help to contain the vapor cloud and control its movement.

5.6 OPERATION AND MAINTENANCE PRACTICES

Quality hardware, contained mechanical equipment, and protective devices all increase plant safety; however, they must be supported by the safety policies of management and by constraints on their operation and maintenance. This section describes how management policy and training, operation, and maintenance procedures relate to the prevention of accidental hydrogen cyanide releases. Within the chemical industry, these procedures and practices vary

widely because of differences in the size and nature of the processes and because any determination of their adequacy is inherently subjective. For this reason, the following subsections focus primarily on fundamental principles and do not attempt to define specific policies and procedures.

5.6.1 Management Policy

Management is a key factor in the control of industrial hazards and the prevention of accidental releases. Management establishes the broad policies and procedures which influence the implementation and execution of specific hazard control measures. It is important that these management policies and procedures be designed to match the level of risk in the facilities where they will be used. Most organizations have a formal safety policy. Many make policy statements to the effect that safety must rank equally with other company functions such as production and sales. The effectiveness of any safety program, however, is determined by a company's commitment to it, as demonstrated throughout the management structure. Specific goals must be derived from the safety policy and supported by all levels of management. Safety and loss prevention should be an explicit management objective. Ideally, management should establish the specific safety performance measures, provide incentives for attaining safety goals, and commit company resources to safety and hazard control. The advantages of an explicit policy are that it sets the standard by which existing programs can be judged, and it provides evidence that safety is viewed as a significant factor in company operations.

In the context of accident prevention, management is responsible for (29,36):

- Ensuring worker competency;
- Developing and enforcing standard operating procedures;
- Adequate documentation of policy and procedures;

- Communicating and promoting feedback regarding safety issues;

- Identification, assessment, and control of hazards; and

- Regular plant audits and provisions for independent checks.

Additional discussion on the responsibilities of management will be found in a manual on control technologies, part of this manual series.

5.6.2 Operator Training

The performance of operating personnel is a key factor in the prevention of accidental chemical releases. Many case studies documenting industrial incidents note the contribution of human error to accidental releases (29). Release incidents may be caused by using improper routine operating procedures, by insufficient knowledge of process variables and equipment, by lack of knowledge about emergency or upset procedures, by failure to recognize critical situations, and in some cases by direct physical mistake (e.g., turning the wrong valve). A comprehensive operator training program can decrease the potential for accidents resulting from such causes.

Operator training can include a wide range of activities and a broad spectrum of information. Training, however, is distinguished from education in that it is specific to particular tasks. While general education is important and beneficial, it is not a substitute for specific training. The content of a specific training program depends on the type of industry, the nature of the processes used, the operational skills required, the characteristics of the plant management system, and tradition.

Some general characteristics of quality industrial training programs include:

- Establishment of good working relations between management and personnel;

- Definition of trainer responsibilities and training program goals;

- Use of documentation, classroom instruction, and field training (in some cases supplemented with simulator training);

- Inclusion of procedures for normal startup and shutdown, routine operations, and upsets, emergencies, and accidental releases; and

- Frequent supplemental training and the use of up-to-date training materials.

In many instances training is carried out jointly by plant managers and a training staff selected by management. In others, management is solely responsible for maintaining training programs. In either case, responsibilities should be explicitly designated to ensure that the quality and quantity of training provided is adequate. Training requirements and practices can be expected to differ between small and large companies, partly because of resource needs and availability, and partly because of differences in employee turnover.

A list of the aspects typically involved in the training of process operators for routine process operations is presented in Table 5-4.

Emergency training includes topics such as:

- Recognition of alarm signals;

TABLE 5-4. ASPECTS OF TRAINING PROGRAMS FOR ROUTINE PROCESS OPERATIONS

Process goals, economics, constraints, and priorities
Process flow diagrams
Unit operations
Process reactions, thermal effects
Control systems
Process materials quality, yields
Process effluents and wastes
Plant equipment and instrumentation
Equipment identification
Equipment manipulation
Operating procedures
Equipment maintenance and cleaning
Use of tools
Permit systems
Equipment failure, services failure
Fault administration
    Alarm monitoring
    Fault diagnosis
    Malfunction detection
Communications, recordkeeping, reporting

Source: Reference 29.

- Performance of specific functions (e.g., shutdown switches);
- Use of specific equipment;
- Actions to be taken on instruction to evacuate;
- Fire fighting; and
- Rehearsal of emergency situations.

Aspects specifically addressed in safety training include (29,36):

- Hazard recognition and communication,
- Actions to be taken in particular situations,
- Available safety equipment and locations,
- When and how to use safety equipment,
- Use and familiarity with documentation such as,
  - plant design and operating manuals,
  - company safety rules and procedures,
  - procedures relevant to fire, explosion, accident, and health hazards,
  - chemical property and handling information, and
- First aid and CPR.

Although emergency and safety programs typically focus on incidents such as fires, explosions, and personnel safety, it is important that prevention of accidental chemical releases and release responses be addressed as part of these programs.

Much of the type of training discussed above is also important for management personnel. Safety training gives management the perspective necessary to formulate good policies and procedures, and to make changes that will improve the quality of plant safety programs. Lees suggests that training programs applied to managers include or define (29):

- Overview of technical aspects of safety and loss prevention approach,
- Company systems and procedures,
- Division of labor between safety personnel and managers in with respect to training, and
- Familiarity with documented materials used by workers.

5.6.3 Maintenance and Modification Practices

Plant maintenance is necessary to ensure the structural integrity of chemical processing equipment; modifications are often necessary to allow more effective production. However, since these activities are also a primary source of accidental release incidents, proper maintenance and modification practices are an important part of accidental release prevention. Use of a formal system of controls is perhaps the most effective way of ensuring that maintenance and modification are conducted safely. In many cases, control systems have had a marked effect on the level of failures experienced (29).

Permit systems and up-to-date maintenance procedures minimize the potential for accidents during maintenance operations. Permit-to-work systems control maintenance activities by specifying the work to be done, defining individual responsibilities, eliminating or protecting against hazards, and ensuring that appropriate inspection and testing procedures are followed.

Maintenance permits originate with the operating staff. Permits may be issued in one or two stages. In one-stage systems, the operations supervisor issues permits to the maintenance supervisor, who is then responsible for his staff. Two-stage systems involves a second permit issued by the maintenance supervisor to his workforce (29).

Another form of maintenance control is the maintenance information system. Ideally, these systems should log the entire maintenance history of equipment, including preventative maintenance, inspection and testing, routine servicing, and breakdown or failure maintenance. This type of system is also used to track incidents caused by factors such as human error, leaks, and fires, including identification and quantification of failures responsible for hazardous conditions, failures responsible for downtime, and failures responsible for direct repair costs.

Accidental releases are frequently the result of some aspect of plant modification. Accidents result when equipment integrity and operation are not properly assessed following modification, or when modifications are made without updating corresponding operation and maintenance instructions. In these situations, it is important that careful assessment of the modification results has a priority equal to that of getting the plant on-line.

For effective modification control, there must be established procedures for authorization, work activities, inspection, and assessment, complete documentation of changes, including the updating of manuals, and additional training to familiarize operators with new equipment and procedures (29,34).

Formal procedures and checks on maintenance and modification practices must be established to ensure that such practices enhance rather than adversely affect plant safety. As with other plant practices, procedure development and complete documentation are necessary. However, training, attitude, and the degree to which the procedures are followed also significantly influence plant safety and release prevention.

The use and availability of clearly defined procedures collected in maintenance and operating manuals is crucial for the prevention of accidental releases. Well written instructions should give enough information about a process that the worker with hands on responsibility for operating or maintaining the process can do so safely, effectively, and economically. These instructions not only document the path to the desired results, but also are the basis for most industrial training programs (37,38). In the chemical industry, operating and maintenance manuals vary in content and detail. To some extent, this variation is a function of process type and complexity; however, in many cases it is a function of management policy. Because of their importance to the safe operation of a chemical process, these manuals must be as clear, straightforward, and complete as possible. In addition, standard procedures should be developed and documented before plant startup, and appropriate revisions should be made throughout plant operations.

Operation and maintenance may be combined or documented separately. Procedures should include startup, shutdown, hazard identification, upset conditions, emergency situations, inspection and testing, and modifications (29). Several authors think industrial plant operating manuals should include (29,36,37,38):

- Process descriptions;
- A comprehensive safety and occupational health section;
- Information regarding environmental controls;
- Detailed operating instructions, including startup and shutdown procedures;
- Upset and emergency procedures;
- Sampling instructions;

- Operating documents (e.g., logs, standard calculations);
- Procedures related to hazard identification;
- Information regarding safety equipment;
- Descriptions of job responsibilities; and
- Reference materials.

Plant maintenance manuals typically contain procedures not only for routine maintenance, but also for inspection and testing, preventive maintenance, and plant or process modifications. These procedures include specific items such as codes and supporting documentation for maintenance and modifications (e.g., permits to work, clearance certificates), equipment identification and location guides, inspection and lubrication schedules, information on lubricants, gaskets, valve packings and seals, maintenance stock requirements, standard repair times, equipment turnaround schedules, and specific inspection codes (e.g., for vessels and pressure systems) (29). Full documentation of the maintenance required for protective devices is a particularly important aspect of formal maintenance systems.

The preparation of operating and maintenance manuals, their availability, and the familiarity of workers with their contents are all important to safe plant operations. The objective, however, is to maintain this safe practice throughout the life of the plant. Therefore, as processes and conditions are modified, documented procedures must also be modified.

5.7 CONTROL EFFECTIVENESS

It is difficult to quantify the control effectiveness of preventive and protective measures to reduce the probability and magnitude of accidental releases. Preventive measures, which may involve numerous combinations of process design, equipment design, and operational measures, are especially

difficult to quantify because they reduce the probability of a release rather than a physical quantity of chemical. Protective measures are more analogous to traditional pollution control technologies. Thus they may be easier to quantify in terms of their efficiency in reducing a quantity of chemical that could be released.

Preventive measures reduce the probability of an accidental release by increasing the reliability of process systems operations and equipment. Control effectiveness can thus be expressed for both of the qualitative improvements achieved and quantitative improvements as probabilities. Table 5-5 summarizes what appear to be major design, equipment, and operational measures applicable to the primary hazards identified for the hydrogen cyanide applications in the U.S. The items listed in Table 5-5 are for illustration only and do not necessarily represent a satisfactory control option for all cases. These control options appear to reduce the risk associated with an accidental release when viewed from a broad perspective. However, there are undoubtedly specific cases where these control options will not be appropriate. Each case must be evaluated individually. A presentation of more information about reliability in terms of probabilities is planned in other volumes of the prevention reference manual series.

5.8 ILLUSTRATIVE COST ESTIMATES FOR CONTROLS

This section presents cost estimates for different levels of control and for specific release prevention and protection measures for hydrogen cyanide storage and process facilities that might be found in the United States.

5.8.1 Prevention and Protection Measures

Preventive measures reduce the probability of an accidental release from a process or storage facility by increasing the reliability of both process systems operations and equipment. Along with an increase in the reliability of a system is an increase in the capital and annual costs associated with incorporating prevention and protection measures into a system. Table 5-6

TABLE 5-5. EXAMPLES OF MAJOR PREVENTION AND PROTECTION MEASURES FOR HYDROGEN CYANIDE RELEASES

Hazard Area	Prevention/Protection
Temperature control of cyanide manufacturing reactor	Redundant temperature sensors; interlock feed flow to high temperature signal. Interlock preheater heating fluid flow to high temp signal. Pressure relief valve discharge sent to flare.
Flow control where acid stabilizer is added to hydrogen cyanide.	Redundant flow control loops; acid addition line sized to restrict maximum possible flow.
Flow/composition control to continuous reactor using hydrogen cyanide.	Redundant flow control loops; composition monitoring; level monitoring.
Overpressure	Redundant pressure relief; not isolatable; adequate size; discharge not restricted.
Corrosion	Increased monitoring with more frequent inspections; use of pH sensing on cooling water and steam condensate loops; use of corrosion coupons; visual inspections; non-destructive testing.
Reactor and reboiler temperatures	Redundant temperature sensing and alarms.
Overfilling	Redundant level sensing, alarms and interlocks; training of operators.
Atmosphere releases from relief discharges	Emergency vent scrubber system.
Storage tank or line rupture	Enclosure vented to emergency scrubber system; diking; foams; dilution; neutralization; water sprays.

(continued)

TABLE 5-5 (Continued)

Hazard Area	Prevention/Protection
Human error	Increased training and supervision; use of checklists; use of automatic systems.
External fire	Water sprays to cool exposed hydrogen cyanide storage vessels; siting away from other flammables; storage tank refrigeration systems.

TABLE 5-6. ESTIMATED TYPICAL COSTS OF MAJOR PREVENTION AND PROTECTION MEASURES FOR HYDROGEN CYANIDE RELEASES

Prevention/Protection Measure	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Continuous moisture monitoring	7,500-10,000	900-1,300
Flow control loop	4,000-6,000	500-750
Temperature sensor	250-400	30-50
Pressure relief[a]		
- relief valve	1,000-2,000	120-250
- rupture disk	1,000-1,200	120-150
Interlock system for flow shut-off	1,500-2,000	175-250
pH monitoring	7,500-10,000	900-1,300
Alarm system	250-500	30-75
Level sensor		
- liquid level gauge	1,500-2,000	175-250
- load cell	10,000-15,000	1,300-1,900
Diking (based on a 10,000 gal. tank)		
- 3 ft. high	1,200-1,500	150-175
- top of tank height (10 ft.)	7,000-7,500	850-900
Increased corrosion inspection		200-400

[a]Costs shown are for pressure relief device only and do not include other equipment items such as piping to scrubbers or flares.

presents costs for some of the major design, equipment, and operational measures applicable to the primary hazards identified in Table 5-5 for the hydrogen cyanide applications in the United States.

5.8.2 Levels of Control

Prevention of accidental releases relies on a combination of technological, administrative, and operational practices as they apply to the design, construction, and operation of facilities where hazardous chemicals are used and stored. Inherent in determining the degree to which these practices are carried out is their costs. At a minimum, equipment and procedures should be in accordance with applicable codes, standards, and regulations. However, additional measures can be taken to provide extra protection against an accidental release.

The levels of control concept provides a means of assigning costs to increased levels of prevention and protection. At the lower end of the tier is the "Baseline" system. This system consists of the elements required for normal safe operation and basic prevention of an accidental release of hazardous material.

The second level of control is "Level 1". "Level 1" includes the baseline system with added modifications such as improved materials of construction, additional controls, and generally more extensive release prevention measures. The costs associated with this level are higher than the baseline system costs.

The third level of control is "Level 2". This system incorporates both the "Baseline" and "Level 1" systems with additional modifications designed specifically for the prevention of an accidental release such as alarm and interlock systems. The extra accidental release prevention measures incorporated into "Level 2" are reflected in its cost, which is much higher than that of the baseline system.

When comparing the costs of the various levels of control, it is important to realize that higher costs do not necessarily imply improved safety. The measures applied must be applied correctly. Inappropriate modifications or add-ons may not make a system safer. Each added control option increases the complexity of a system. In some cases the hazards associated with the increased complexity may outweigh the benefits derived from the particular control option. Proper design and construction along with proper operational practices are needed to assure safe operation.

These estimates are for illustrative purposes only. It is doubtful that any specific installation would find all of the control options listed in these tables appropriate for their purposes. An actual system is likely to incorporate some items from each of the levels of control and also some control options not listed here. The purpose of these estimates is to illustrate the relationship between cost and control, and is not to provide an equipment check list.

Levels of control cost estimates were prepared for a 29 ton fixed hydrogen cyanide storage tank system with a 10,000 gallon capacity and a 2,000 gal. sodium cyanide reactor system. These systems are representative of storage and process facilities that might be found in the United States.

5.8.3 Summary of Levels of Control

Table 5-7 presents a summary of the total capital and annual costs for each of the three levels of controls for the hydrogen cyanide storage system and the sodium cyanide reaction system. The costs presented correspond to the systems described in Table 5-8 and Table 5-9. Each of the level costs include the cost of the basic system plus any added controls. Specific cost information and breakdown for each level of control for both the storage and process facilities are presented in Tables 5-10 through 5-15.

TABLE 5-7. SUMMARY COST ESTIMATES OF POTENTIAL LEVELS OF CONTROLS FOR HYDROGEN CYANIDE STORAGE TANK AND SODIUM CYANIDE REACTOR

System	Level of Control	Total Capital Cost (1986 $)	Total Annual Cost (1986 $/yr)
Hydrogen Cyanide Storage Tank; 29 ton Fixed Storage Tank with 10,000 Gallon Capacity.	Baseline	100,000	12,000
	Level No. 1	141,000	17,000
	Level No. 2	360,000	43,000
Sodium Cyanide Reactor System 2,000 Gallon Continuous Reactor	Baseline	147,000	18,000
	Level No. 1	221,000	28,000
	Level No. 2	417,000	51,000

TABLE 5-8. EXAMPLE OF LEVELS OF CONTROL FOR HYDROGEN CYANIDE STORAGE TANK
Process: 29 Ton Fixed Hydrogen Cyanide Storage Tank - 10,000 gallon

Controls	Baseline	Level No. 1	Level No. 2
Flow:	Single check valve on tank process feed line.	Add second check valve.	Add a reduced - pressure device with internal air gap and relief vent to containment tank or scrubber.
Temperature:	Temperature indicator and alarm.	Add remote indicator.	Add redundant sensors and alarms.
Pressure:	Single pressure relief valve, vent to flare. Pressure vacuum recorder alarm.	Add second relief valve, secure non-isolatable. Vent to flare.	Add redundant alarms. Add rupture disks under relief valves.
Quantity:	Local level indicators and alarms.	Add remote indicator.	Add redundant alarms and high-low level interlock shut-off for both inlet and outlet lines.
Location:	Away from traffic, flammables, and other hazardous processes.	Same	Same
Materials of Construction:	Carbon steel.	Carbon steel with increased corrosion allowance (1/16 inch).	Stainless steel, Type 316.

(continued)

TABLE 5-8 (Continued)

Controls	Baseline	Level No. 1	Level No. 2
Vessel:	Tank pressure specification: 25 psig	Same	Tank pressure Specification: 50 psig.
Piping:	Schedule 40, stainless steel	Schedule 80, stainless steel	Schedule 80 Monel®
Process Machinery:	Type 316 stainless steel submerged pumps.	Same	Same
Enclosures:	None	None	Steel Building
Diking:	3 ft. high dike	Top of tank height, 10 ft.	--
Release Protection:	Shared flare system.	Same	Dedicated flare system.
Mitigation:	None	Foam system.	Same

TABLE 5-9. EXAMPLE OF LEVELS OF CONTROL FOR SODIUM CYANIDE MANUFACTURE
Process: Continuous sodium cyanide reactor
Typical Operating Conditions: - Temperature: 140°F
- Pressure: 100 mm Hg

Controls	Baseline	Level No. 1	Level No. 2
Process:	Use of acid stabilizing system.	Operate reactor at a lower temperature.	Use of interlocks and backup cooling systems.
Temperature:	Provide temperature control with remote temperature indication and alarms.	Add redundant temperature sensors and alarms. Automatic switch to a cooling system.	Add backup cooling system.
Pressure:	Provide remote control on vacuum system with remote pressure sensing. Single pressure relief valve to a shared flare system.	Add redundant remote pressure sensing and control with alarms. Add second relief valve. Vent to shared flare system.	Add rupture disks under relief valves. Vent to dedicated flare.
Flow:	Provide remote flow control on NaOH and HCN feed streams and on heating medium flow control.	Add redundant flow control loops.	Add automatic shut-off of feeds and automatic switch from heating to cooling medium.
Corrosion:	Provide periodic visual inspection.	Add increased monitoring with periodic ultronsonic inspection.	Add increased monitoring with more frequent testing.
Composition:	None	Provide periodic testing for HCN polymer formation in reactor vessel.	Periodic testing for HCN polymer formation in reactor vessel and in HCN feed.

(Continued)

TABLE 5-9 (Continued)

Controls	Baseline	Level No. 1	Level No. 2
Material of Construction:	Type 316 stainless steel-clad carbon steel.	Type 316 stainless steel-clad carbon steel with increase corrosion allowance.	Monel® - clad carbon steel.
Vessel:	Pressure specification: Full vacuum, 50 psig pressure.	Pressure specification: Full vacuum, 100 psig pressure.	Pressure specification: Full vacuum, 150 psig pressure.
Piping:	Schedule 40 Type 316 stainless steel.	Schedule 80 Type 316 stainless steel.	Schedule 80 Monel®
Process Machinery:	Centrifugal pump, Type 316 stainless steel, double mechanical seal.	Same.	Centrifugal pump, Monel® construction, double mechanical seal.
Protective Barrier:	Curbing around reactor.	3 ft. high retaining wall.	--
Enclosure:	None.	None.	Steel building.
Flare:	Shared flare system.	Same.	Dedicated flare system.

TABLE 5-10. CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE HYDROGEN CYANIDE STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Storage Tank	33,000	3,806
Piping and Valves:		
Pipework	10,000	1,100
Check Valves	530	60
Globe Valves (20)	8,100	950
Relief Valve	1,600	190
Process Machinery:		
Submergible Pumps (2)	13,000	1,500
Refrigeration System	22,000	2,500
Instrumentation:		
Local Temperature Indicator	1,900	220
Temperature Alarm	380	45
Pressure Gauges (2)	1,485	170
Pressure Alarm	380	45
Liquid Level Indicator	1,900	220
Level Alarm	380	45
Flare System:	4,500	520
Diking:		
Three-Foot High Concrete Dike	1,300	160
Procedures and Practices:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		15
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		30
Valve Maintenance		350
TOTAL COSTS	100,000	12,000

TABLE 5-11. CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 HYDROGEN CYANIDE STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Storage Tank	54,000	6,200
Piping and Valves:		
Pipework	15,000	1,800
Check Valves (2)	1,000	120
Globe Valves (20)	8,100	950
Relief Valve (2)	3,900	450
Process Machinery:		
Submergible Pumps (2)	13,000	1,500
Refrigeration System	22,000	2,500
Instrumentation:		
Local Temperature Indicator	1,900	220
Remote Temperature Indicator	2,200	260
Temperature Alarm	380	45
Temperature Sensor	380	45
Pressure Gauges (2)	1,485	170
Pressure Alarm	380	45
Liquid Level Indicator	1,900	220
Remote Level Indicator	2,200	260
Level Alarm	380	45
Flare System:	5,100	590
Diking:		
Ten-Foot High Concrete Dike	7,600	880
Procedures and Practices:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		15
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		30
Valve Maintenance		350
TOTAL COSTS	141,000	17,000

TABLE 5-12. CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 HYDROGEN CYANIDE STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Storage Tank	240,000	28,000
Piping and Valves:		
Pipework	20,000	2,400
Check Valves (2)	1,000	120
Globe Valves (20)	8,100	950
Relief Valve (2)	3,900	450
Rupture Disks (2)	1,100	130
Process Machinery:		
Submergible Pumps (2)	13,000	1,500
Refrigeration System	22,000	2,500
Instrumentation:		
Local Temperature Indicator	1,900	220
Remote Temperature Indicator	2,200	260
Temperature Alarms (2)	760	90
Temperature Sensor	380	45
Pressure Gauges (2)	1,485	170
Pressure Alarms (2)	760	90
Liquid Level Indicator	1,900	220
Remote Level Indicator	2,200	260
Level Alarms (2)	760	90
High-low Level Shutoff	1,900	220
Flare System:	22,000	2,600
Diking:		
Three-Foot High Concrete Dike	1,400	160
Enclosures:		
Steel Building	10,000	1,200
Procedures and Practices:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		15
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		30
Valve Maintenance		350
TOTAL COSTS	360,000	43,000

TABLE 5-13. CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE SODIUM CYANIDE REACTOR SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Reactor	84,000	10,000
Heat Exchanger	800	95
Piping and Valves:		
Pipework	10,000	1,100
Glove Valves (20)	8,100	950
Relief Valve	1,600	190
Process Machinery:		
Centrifugal Pump	6,300	760
Instrumentation:		
Remote Temperature Indicator	2,200	260
Temperature Alarm	380	45
Temperature Control:		
Controller	1,800	220
Sensor	380	45
Control Valve	2,700	320
Remote Pressure Indicator	2,200	260
Pressure Alarm	380	45
Flow Control Loops (3):		
Controller	5,400	650
Flowmeter	6,800	850
Control Valve	8,400	1,000
Flare System:	4,500	520
Diking:		
Curbing Around Reactor	910	110
Procedures and Practices:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		15
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		30
Valve Maintenance		350
TOTAL COSTS	147,000	18,000

TABLE 5-14. CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 SODIUM CYANIDE REACTOR SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Reactor	153,000	18,000
Heat Exchanger	800	95
Piping and Valves:		
Pipework	10,000	1,100
Glove Valves (20)	8,100	950
Relief Valves (2)	3,200	380
Process Machinery:		
Centrifugal Pump	6,300	760
Instrumentation:		
Remote Temperature Indicator	2,200	260
Temperature Alarms (2)	760	90
Temperature Sensor	380	45
Temperature Control:		
Controller	1,800	220
Sensor	380	45
Control Valve	2,700	320
Temperature Switch	540	65
Remote Pressure Indicators (2)	4,300	520
Pressure Control:		
Controller	1,800	220
Sensor	380	45
Control Valve	2,700	320
Pressure Alarms (2)	760	90
Flow Control Loops (3):		
Controller	5,400	650
Flowmeter	1,400	850
Control Valve	8,400	1,000
Flare System:	4,500	520
Diking:		
Three-Foot High Retaining Wall	1,300	200
Procedures and Practices:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		15
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		30
Valve Maintenance		350
TOTAL COSTS	221,000	28,000

TABLE 5-15. CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 SODIUM CYANIDE REACTOR SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Reactor	300,000	36,000
Heat Exchanger	790	95
Piping and Valves:		
Pipework	18,700	2,200
Glove Valves (20)	8,500	950
Relief Valves (2)	3,400	380
Rupture Disks (2)	1,100	130
Process Machinery:		
Centrifugal Pump	9,300	1,100
Instrumentation:		
Remote Temperature Indicator	2,200	260
Temperature Alarms (2)	780	90
Temperature Sensor	350	45
Temperature Control:		
Controller	1,800	220
Sensor	390	45
Control Valve	2,800	320
Temperature Switch	540	65
Remote Pressure Indicators (2)	4,300	520
Pressure Control:		
Controller	1,800	220
Sensor	390	45
Control Valve	2,800	320
Pressure Alarms (2)	780	90
Flow Control Loops (3):		
Controller	5,400	650
Flowmeter	7,000	850
Control Valve	8,400	1,000
Flow Interlock Systems (2)	3,900	430
Flare System:	22,000	2,600
Diking:		
Three-Foot High Retaining Wall	1,600	200

(Continued)

TABLE 5-15 (Continued)

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Enclosure:		
Steel Building	8,400	1,000
Procedures and Practices:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		15
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		30
Valve Maintenance		350
TOTAL COSTS	417,000	51,000

5.8.4 Equipment Specifications and Detailed Costs

Equipment specifications and details of the capital cost estimates for the hydrogen cyanide storage and the sodium cyanide reactor systems are presented in Tables 5-16 through 5-23.

5.8.5 Methodology

Format for Presenting Costs Estimates--

Tables are provided for control schemes associated with storage and process facilities for hydrogen cyanide showing capital, operating, and total annual costs. The tables are broken down into subsections comprising vessels, piping and valves, process machinery, instrumentation, and procedures and practice. The presentation of the costs in this manner allows for easy comparison of costs for specific items, different levels, and different systems.

Capital Cost--All capital costs presented in this report are shown as total fixed capital costs. Table 5-24 defines the cost elements comprising total fixed capital as it is used here.

The computation of total fixed capital as shown in Table 5-24 begins with the total direct cost for the system under consideration. This total direct cost is the total direct installed cost of all capital equipment comprising the system. Depending on the specific equipment item involved, the direct capital cost was available or was derived from uninstalled equipment costs by computing costs of installation separately. To obtain the total fixed capital cost, other costs obtained by utilizing factors are added to the total direct costs.

The first group of other cost elements is indirect costs. These include engineering and supervision, construction expenses, and various other expenses such as administration expenses, for example. These costs are computed by multiplying total direct costs by a factor shown in Table 5-24. The factor is

TABLE 5-16. EQUIPMENT SPECIFICATIONS ASSOCIATED WITH HYDROGEN CYANIDE STORAGE SYSTEM

Equipment Item	Equipment Specification		Reference
VESSEL:			
Storage tank	Baseline:	10,000 gal. ASTM A516 grade 60 carbon steel, 25 psig rating	39, 40, 41, 42
	Level #1:	10,000 gal. carbon steel with 1/8 inch corrosion protection, 25 psig pressure rating	
	Level #2:	10,000 gal., Type 316 stainless steel, 50 psig pressure rating	
PIPING & VALVES			
Pipework	Baseline:	100 ft. of 2 in. Schedule 40 Type 316 stainless steel	43
	Level #1:	100 ft. of 2 in. Schedule 80 Type 316 stainless steel	
	Level #2:	100 ft. of 2 in. Schedule 80 Monel®	
Check Valve	2 in. vertical lift check valve, stainless steel construction		40, 44
Globe Valve	2 in. ANSI Class 300, Type 316 stainless steel body		39, 40, 44
Relief Valve	1 in. x 2 in., ANSI Class 300 inlet and outlet flange, angle body, closed bonnet with screwed cap, Type 316 stainless steel body and trim		40
Reduced Pressure Device	Double check valve type device with internal air gap and relief valve		39
Rupture Disk	1 in. Type 316 stainless steel and carbon steel holder		39, 41, 45
PROCESS MACHINERY:			
Submerged Pump	Type 316 stainless steel, submergible pump, 100 gpm capacity		39, 46

(Continued)

TABLE 5-16 (Continued)

Equipment Item	Equipment Specification	Reference
INSTRUMENTATION		
Local Temperature Indicator	Thermocouple, thermowell, and electronic indicator /recorder	39, 40, 47
Remote Temperature Indicator	Transmitter and associated electronic indicator/recorder	39, 47
Temperature Sensor	Thermocouple and associated thermowell	39, 40, 47
Temperature Alarm	Indicating and audible alarm	40, 46, 48
Pressure Gauge	Diaphragm sealed, Type 316 stainless steel diaphragm, 0-100 psig rating	39, 40, 47
Pressure Alarm	Indicating and audible alarm	40, 46, 48
Level Alarm	Indicating and audible alarm	40, 46, 48
Level Indicator	Electrical differential pressure type indicator	39, 46
High-Low Level Shut-off	Solenoid valve, switch and relay system	39, 40, 46, 47
ENCLOSURE:		
Building	Level #2: 26-gauge steel walls and roof, door, ventilation system	46
DIKING:	Baseline: 6 in. concrete walls, 3 ft. high	46
	Level #1: 10 in. concrete walls, top of tank height (10 ft.)	

(Continued)

TABLE 5-16 (Continued)

Equipment Item	Equipment Specification	Reference
FLARE:	Baseline and Level #1: Elevated flare system based on a release rate of 4,600 lb/hr and a shared system with a total of five units Level #2: Elevated flare system based on above flow-rate and a dedicated unit for only this storage facility	49

TABLE 5-17. MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE HYDROGEN CYANIDE STORAGE SYSTEM

	1986 Dollars				
	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
Vessels:					
Storage Tank	15,000	6,800	22,000	7,700	33,000
Piping and Valves:					
Pipework	3,800	2,600	6,400	2,200	10,000
Check Valve	300	50	350	130	530
Globe Valves (20)	5,000	500	5,500	1,900	8,100
Relief Valve	1,000	50	1,100	380	1,600
Process Machinery:					
Submergible Pumps (2)	6,000	2,600	8,600	3,000	13,000
Refrigeration System	10,000	4,500	14,500	5,000	22,000
Instrumentation:					
Local Temperature Indicator	1,000	250	1,250	440	1,900
Temperature Alarm	200	50	250	90	380
Pressure Gauges (2)	800	200	1,000	350	1,485
Pressure Alarm	200	50	250	90	380
Liquid Level Indicator	1,000	250	1,250	440	1,900
Level Alarm	200	50	250	90	380
Flare System:	2,000	1,000	3,000	1,100	4,500
Diking:					
Three-foot High Concrete Dike	390	510	900	320	1,300
TOTAL COSTS	47,000	20,000	97,000	23,000	100,000

TABLE 5-18. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 HYDROGEN CYANIDE STORAGE SYSTEM

	1986 Dollars				
	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
Vessels:					
Storage Tank	25,000	11,000	36,000	13,000	54,000
Piping and Valves:					
Pipework	5,000	5,200	10,200	3,600	15,000
Check Valves (2)	600	100	700	250	1,000
Globe Valves (20)	500	500	5,500	1,900	8,100
Relief Valves (2)	2,500	100	2,600	900	3,900
Process Machinery:					
Submergible Pumps (2)	6,000	2,600	8,600	3,000	13,000
Refrigeration System	10,000	4,500	14,500	5,000	22,000
Instrumentation:					
Local Temperature Indicator	1,000	250	1,250	440	1,900
Remote Temperature Indicator	1,200	300	1,500	530	2,200
Temperature Alarm	200	50	250	90	380
Temperature Sensor	200	50	250	90	380
Pressure Gauges (2)	800	200	1,000	350	1,485
Pressure Alarm	200	50	250	90	380
Liquid Level Indicator	1,000	250	1,250	440	1,900
Remote Level Indicator	1,200	300	1,500	530	2,200
Level Alarm	200	50	250	90	380
Flare System:	3,000	1,400	3,400	1,200	5,100
Diking:					
Ten-foot High Concrete Dike	2,200	2,900	5,100	1,800	7,600
TOTAL COSTS	65,000	30,000	95,000	33,000	141,000

TABLE 5-19. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 HYDROGEN CYANIDE STORAGE SYSTEM

	1986 Dollars				
	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
Vessels:					
Storage Tank	110,000	50,000	160,000	56,000	24,000
Piping and Valves:					
Pipework	8,000	5,000	14,000	5,000	20,000
Check Valves (2)	600	100	700	250	1,000
Globe Valves (20)	5,000	500	5,500	1,900	8,100
Relief Valves (2)	2,500	100	2,600	900	3,900
Rupture Disks (2)	650	75	725	260	1,100
Process Machinery:					
Submergible Pumps (2)	6,000	2,600	8,600	3,000	13,000
Refrigeration System	10,000	4,500	14,500	5,000	22,000
Instrumentation:					
Local Temperature Indicator	1,000	250	1,250	440	1,900
Remote Temperature Indicator	1,200	300	1,500	530	2,200
Temperature Alarms (2)	400	100	500	180	760
Temperature Sensor	200	50	250	90	380
Pressure Gauges (2)	800	200	1,000	350	1,485
Pressure Alarms (2)	400	100	500	180	760
Liquid Level Indicator	1,000	250	1,250	440	1,900
Remote Level Indicator	1,200	300	1,500	530	2,200
Level Alarm (s)	400	100	500	180	760
High-Low Level Shutoff	1,000	250	1,250	440	1,900
Flare System:	10,000	5,000	15,000	5,300	22,000
Diking:					
Three-Foot High Concrete Dike	390	520	910	320	1,400
Enclosures:					
Steel Building	4,600	2,300	6,900	2,400	10,000
TOTAL COSTS	165,000	73,000	238,000	84,000	360,000

TABLE 5-20. EQUIPMENT SPECIFICATIONS ASSOCIATED WITH SODIUM CYANIDE REACTOR SYSTEM

Equipment Item	Equipment Specification	Reference
VESSEL:		
Reactor	Baseline: 2,000 gal. Type 316 stainless steel-clad carbon steel, full vacuum - 50 psig rating Level #1: Same as baseline with added corrosion allowance and full vacuum - 100 psig rating Level #2: 2,000 gal. Monel® clad carbon steel, full vacuum - 150 psig rating	39, 40, 41, 42
Heat Exchanger	Type 316 stainless steel construction, 20 ft.^{2} of surface area, shell and tube type	39
PIPING AND VALVES:		
Pipework	Baseline: 100 ft. of 2 inch Schedule Type 316 stainless steel Level #1: 100 ft. of 2 inch Schedule 80 Type 316 stainless steel Level #2: 100 ft. of 2 inch Schedule 80 Monel®	43
Globe Valve	2 in. ANSI class 300, Type 316 stainless steel body	39, 40, 44
Relief Valve	1 in. x 2 in. ANSI class 300 inlet and outlet flange, angle body, closed bonnet with screwed cap, Type 316 stainless steel body and trim	40
Rupture Dish	1 in. Type 316 stainless steel and carbon steel holder	39, 41, 45
PROCESS MACHINERY:		
Centrifugal Pump	Baseline and Level #1: Single stage, 100 gpm capacity, Type 316 stainless steel construction, double mechanical seal Level #2: Same as above except Monel® construction	40, 50

(Continued)

TABLE 5-20 (Continued)

Equipment Item	Equipment Specification	Reference
INSTRUMENTATION:		
Local Temperature Indicator	Thermocouple, thermowell, and electronic indicator	39, 40, 47
Remote Temperature Indicator	Transmitter and associated electronic indicator	39, 47
Temperature Sensor	Thermocouple and associated thermowell	39, 40, 47
Temperature Alarm	Indicating and audible alarm	34, 46, 48
Temperature Control Loop	PID controller, 2 in. globe control valve of stainless steel construction, and temperature sensor	39, 47
Temperature Switch	Two-stage switch with independently set actuation	39, 47
Pressure Control Loop	PID controller, 2 in. globe control valve of stainless steel construction, pressure sensor	39, 47
Remote Pressure Indicator	Transducer, transmitter, and electronic indicator	39, 47
Flow Control Loop	PID controller, 2 in. globe control valve of stainless steel construction, flowmeter	39, 47
Flow Interlock System	Solenoid valve, switch, and relay system	39, 40, 46
DIKING:	Baseline: 0.5 ft. high concrete curbing Level #1 & 2: 3 ft. high concrete retaining wall	46

(Continued)

TABLE 5-20 (Continued)

Equipment Item	Equipment Specification	Reference
ENCLOSURE:	Level #2: 26 gauge steel walls and roof, door, ventilation system	46
Flare:	Baseline and Level #1: Elevated flare system based on a total release rated 5,000 lb/hr and a shared system with a total of five units. Level #2: Same as above except that system is dedicated only to this system	49

TABLE 5-21. MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE SODIUM CYANIDE REACTOR SYSTEM

	1986 Dollars				
	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
Vessels:					
Reactor	40,000	18,000	58,000	15,000	84,000
Heat Exchanger	500	250	550	140	800
Piping and Valves:					
Pipework	3,800	2,600	6,400	2,200	10,000
Globe Valves (20)	5,000	500	5,500	1,900	8,100
Relief Valve	1,000	50	1,100	380	1,600
Process Machinery:					
Centrifugal Pump	3,000	1,400	4,400	1,100	6,300
Instrumentation:					
Remote Temperature Indicator	1,200	300	1,500	380	2,200
Temperature Alarm	200	50	250	90	380
Temperature Control:					
Controller	1,000	250	1,250	320	1,800
Sensor	200	50	250	90	380
Control Valve	1,500	375	1,875	470	2,700
Remote Pressure Indicator	1,200	300	1,500	380	2,200
Pressure Alarm	200	50	250	90	380
Flow Control Loops (3):					
Controller	3,000	750	3,750	940	5,400
Flowmeter	3,900	1,000	4,900	1,200	6,800
Control Valve	4,500	1,300	5,800	1,500	8,400
Flare System:	2,000	1,000	3,000	1,100	4,500
Diking:					
Curbing Around Reactor	500	130	630	160	910
TOTAL COSTS	73,000	28,000	101,000	27,000	147,000

TABLE 5-22. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 SODIUM CYANIDE REACTOR SYSTEM

	1986 Dollars				
	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
Vessels:					
Reactor	73,000	33,000	106,000	27,000	153,000
Heat Exchanger	500	250	550	140	800
Piping and Valves:					
Pipework	3,800	2,600	6,400	2,200	10,000
Globe Valves (20)	5,000	500	5,500	1,900	8,100
Relief Valves (2)	2,000	100	2,200	760	3,200
Process Machinery:					
Centrifugal Pump	3,000	1,400	4,400	1,100	6,300
Instrumentation:					
Remote Temperature Indicator	1,200	300	1,500	380	2,200
Temperature Alarms (2)	400	100	500	180	760
Temperature Sensor	200	50	250	90	380
Temperature Control:					
Controller	1,000	250	1,250	320	1,800
Sensor	200	50	250	90	380
Control Valve	1,500	375	1,875	470	2,700
Temperature Switch	300	75	375	95	540
Remote Pressure Indicators (2)	2,400	600	3,000	760	4,300
Pressure Control:					
Controller	1,000	250	1,250	320	1,800
Sensor	200	50	250	90	380
Control Valve	1,500	375	1,875	470	2,700
Pressure Alarms (2)	400	100	500	180	760

(Continued)

TABLE 5-22 (Continued)

	1986 Dollars				
	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
Flow Control Loops (3):					
Controller	3,000	750	3,750	940	5,400
Flowmeter	3,900	1,000	4,900	1,200	1,400
Control Valve	4,500	1,300	5,800	1,500	8,400
Flare System:	2,000	1,000	3,000	1,100	4,500
Diking:					
Three-Foot High Retaining Wall	900	230	1,130	290	1,300
TOTAL COSTS	112,000	45,000	157,000	42,000	221,000

TABLE 5-23. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 SODIUM CYANIDE REACTOR SYSTEM

	1986 Dollars				
	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
Vessels:					
Reactor	146,000	66,000	210,000	53,000	300,000
Heat Exchanger	500	250	550	140	790
Piping and Valves:					
Pipework	8,000	5,000	13,000	3,300	18,700
Globe Valves (20)	5,000	500	5,500	1,900	8,500
Relief Valves (2)	2,000	100	2,200	760	3,400
Rupture Disks (2)	650	75	725	260	1,100
Process Machinery:					
Centrifugal Pump	4,500	2,000	6,500	1,600	9,300
Instrumentation:					
Remote Temperature Indicator	1,200	300	1,500	380	2,200
Temperature Alarms (2)	400	100	500	180	780
Temperature Sensor	200	50	250	90	350
Temperature Control:					
Controller	1,000	250	1,250	320	1,800
Sensor	200	50	250	90	390
Control Valve	1,500	375	1,875	470	2,800
Temperature Switch	300	75	375	95	540
Remote Pressure Indicators (2)	2,400	600	3,000	760	4,300
Pressure Control:					
Controller	1,000	250	1,250	320	1,800
Sensor	200	50	250	90	390
Control Valve	1,500	375	1,875	470	2,800
Pressure Alarms (2)	400	100	500	180	780

(Continued)

TABLE 5-23 (Continued)

	1986 Dollars				
	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
Flow Control Loops (3):					
Controller	3,000	750	3,750	940	5,400
Flowmeter	3,900	1,000	4,900	1,200	7,000
Control Valve	4,500	1,300	5,800	1,500	8,400
Flow Interlock Systems (2)	2,000	500	2,500	880	3,900
Flare System:	10,000	5,000	15,000	3,800	22,000
Diking:					
Three-Foot High Retaining Wall	900	230	1,130	290	1,600
Enclosure:					
Steel Building	4,600	1,200	5,800	1,500	8,400
TOTAL COSTS	206,000	86,000	292,000	75,000	417,000

TABLE 5-24. FORMAT FOR TOTAL FIXED CAPITAL COST

Item No.	Item	Cost
1	Total Material Cost	--
2	Total Labor Cost	--
3	Total Direct Cost	Items 1 + 2
4	Indirect Cost Items (Engineering & Construction Expenses)	0.35 x Item 3a
5	Total Bare Module Cost	Items (3 + 4)
6	Contingency	(0.05 x Item 5)b
7	Contractor's Fee	0.05 x Item 5
8	Total Fixed Capital Cost	Items (5 + 6 + 7)

[a]For storage facilities, the indirect cost factor is 0.35. For process facilities, the indirect cost factor is 0.25.

[b]For storage facilities, the contingency cost factor is 0.05. For process facilities, the contingency cost factor is 0.10.

approximate, is obtained from the cost literature, and is based on previous experience with capital projects of a similar nature. Factors can have a range of values and vary according to technology area and for individual technologies within an area. Appropriate factors were selected for use in this report based on judgement and experience.

When the indirect costs are added to the total direct costs, total bare module cost is obtained. Some additional cost elements, such as contractor's fee and contingency are calculated by applying and adding appropriate factors to the total bare module cost as shown in Table 5-24 to obtain the total fixed capital cost.

Annual Cost--Annual costs are obtained for each of the equipment items by applying a factor for both capital recovery and for maintenance expenses to the direct cost of each equipment item. Table 5-25 defines the cost elements and appropriate factors comprising these costs. Additional annual costs are incurred for procedural items such as valve and vessel inspections, for example. When all of these individual costs are added, the total annual cost is obtained.

Sources of Information--

The costs presented in this report are derived from cost information in existing published sources and also from recent vendor information. It was the objective of this effort to present cost levels for hydrogen cyanide process and storage facilities using the best costs for available sources. The primary sources of cost information are Peters and Timmerhaus (39), Chemical Engineering (51), and Valle-Riestra (52) supplemented by other sources and references where necessary. Adjustments were made to update all costs to a June 1986 dollar basis. In addition, for some equipment items, well documented costs were not available and they had to be developed from component costs.

TABLE 5-25. FORMAT FOR TOTAL ANNUAL COST

Item No.	Item	Cost
1	Total Direct Cost	--
2	Capital Recovery on Equipment Items[a]	0.163 x Item 1
3	Maintenance Expense on Equipment Items	0.01 x Item 1
4	Total Procedural Items	--
5	Total Annual Cost	Items (2 + 3 + 4)

[a]Based on a plant life of ten years and an interest rate of ten percent.

Costs in this document reflect the "typical" or "average" representation for specific equipment items. This restricts the use of data in this report to:

- Preliminary estimates used for policy planning,
- Comparison of relative costs of different levels or systems, and
- Approximations of costs that might be incurred for a specific application.

The costs in this report are considered to be "order of magnitude" with a ±50 percent margin. This is because the costs are based on preliminary estimates and many are updated from literature sources. Large departures from the design basis of a particular system presented in this manual or the advent of a different technology might cause the system cost to vary by a greater extent than this. If used as intended, however, this document will provide a reasonable source of preliminary cost information for the facilities covered.

When comparing costs in this manual to costs from other references, the user should be sure the design bases are comparable and that the capital and annual costs as defined here are the same as the costs being compared.

Cost Updating--

All costs in this report are expressed in June 1986 dollars. Costs reported in the literature were updated using cost indices for materials and labor.

Costs expressed in base year dollars may be adjusted to dollars for another year by applying costs indices as shown in the following equation:

$$\text{new base year cost} = \text{old base year cost} \times \frac{\text{new base year index}}{\text{old base year index}}$$

The Chemical Engineering (CE) Plant Cost Index was used in updating cost for this report. For June 1986, the index is 316.3.

Equipment Costs--

Most of the equipment costs presented in this manual were obtained directly from literature sources of vendor information and correspond to a specific design standard. Special cost estimating techniques, however, were used in determining the costs associated with vessels, piping systems, scrubbers, diking, and enclosures. The techniques used are presented in the following subsections of this manual.

Vessels--The total purchased cost for a vessel, as dollars per pound of weight of fabricated unit f.o.b. with carbon steel as the basis (January 1979 dollars) were determined using the following equation from Peters and Timmerhaus (39):

$$\text{Cost} = [50(\text{Weight of Vessel in Pounds})^{-0.34}]$$

The vessel weight is determined using appropriate design equations as given by Peters and Timmerhaus (39) which allow for wall thickness adjustments for corrosion allowances, for example. The vessel weight is increased by a factor of 0.15 for horizontal vessels and 0.20 for vertical vessels to account for the added weight due to nozzles, manholes, and skirts or saddles. Appropriate factors are applied for different materials of construction as given in Peters and Timmerhaus (39). The vessel costs are updated using cost factors. Finally a shipping cost amounting to 10 percent of the purchased cost is added to obtain the delivered equipment cost.

Piping--Piping costs were obtained using cost information and data presented by Yamartino (43). A simplified approach is used in which it is assumed that a certain length of piping containing a given number of valves,

flanges, and fittings is contained in the storage or process facility. The data presented by Yamartino (43) permit cost determinations for various lengths, sizes, and types of piping systems. Using these factors, a representative estimate can be obtained for each of the storage and process facilities.

Diking--Diking costs were estimated using Mean's manual (46) for reinforced concrete walls. The following assumptions were made in determining the costs. The dike contains the entire contents of a tank in the event of a leak or release. Two dike sizes are possible: A three-foot high dike, six inches thick; and a top-of-tank height dike ten inches thick. The tanks are raised off the ground and are volumetrically included in the volume enclosed by the diking. These assumptions facilitate cost determination for any size diking system.

Enclosures--Enclosure costs were estimated using Mean's Manual (46) for both reinforced concrete and steel-walled buildings. The buildings are assumed to enclose the same area and volume as the top-of-tank height dikes. The concrete building is ten inches thick with a 26-gauge steel roof and a metal door. The steel building has 26-gauge roofing and siding and metal door. The cost of a ventilation system was determined using a typical 1,000 scfm unit and doubling the cost to account for duct work and requirements for the safe enclosure of hazardous chemicals.

Flares--Flare costs were estimated using the following equation from Vatavuk (49) based on the use of an elevated flare system for a high Btu gas system.

$$\text{Costs} = 288\ [\text{Mass flow rate of gas}]^{0.398}$$

A release rate of 4,600 lb/hr was assumed for the storage vessel and an appropriate rate was determined for the process system based on the quantity of hazardous chemical present in the system at any one time. For the sodium

cyanide reactor system, a release rate of 1,000 lb/hr was assumed. In addition, the shared systems were based on a combined discharge for five identical units. The dedicated system was based on a single unit. The costs presented are updated to June 1986 dollars.

Installation Factors--

Installation costs were developed for all equipment items included in both the process and storage systems. The costs include both the material and labor costs for installation of a particular piece of equipment. The costs were obtained directly from literature sources and vendor information or indirectly by assuming a certain percentage of the purchased equipment cost through the use of estimating factors obtained from Peters and Timmerhaus (39) and Valle-Riestra (52). Table 5-26 lists the cost factors used or the reference from which the cost was obtained directly. Many of the costs obtained from the literature were updated to June 1986 dollars using a 10 percent per year rate of increase for labor and cost indices for materials associated with installation.

TABLE 5-26. FORMAT FOR INSTALLATION COSTS

Equipment Item	Factor or Reference
VESSELS:	
Storage Tank	0.45
Expansion Tank	0.25
PIPING AND VALVES:	
Pipework	Ref. 41
Reduced Pressure Device	Ref. 38
Check Valves	Ref. 38
Globe Valves	Ref. 38
Relief Valves	Ref. 38
Rupture Disks	Ref. 38
PROCESS MACHINERY:	
Centrifugal Pump	0.43
Gear Pump	0.43
INSTRUMENTATION:	
All Instrumentation Items	0.25
ENCLOSURES:	Ref. 44
DIKING:	Ref. 44
SCRUBBERS:	0.45

SECTION 6

REFERENCES

1. Chemical Profile, Hydrogen Cyanide. Chemical Marketing Reporter. Schnell Publishing Company Inc., June 4, 1984.

2. Mark, Herman F., Othmer, Donald F., Overberger, Charles G., Seaborg, Glenn T. Kirk-Othmer Encyclopedia of Chemical Technology, 3rd edition, Volume 7, John Wiley & Sons, 1983.

3. Hydrogen Cyanide Storage and Handling. E.I. du Pont de Nemours & Company, Incorporated, Wilmington, DE, 1983.

4. Dean, J. (ed.). Lange's Handbook of Chemistry. Twelfth Edition, McGraw-Hill Book Company, New York, NY, 1979.

5. Chemical Emergency Preparedness Program Interim Guidance, Chemical Profiles, 2 volumes. U.S. Environmental Protection Agency, Washington, DC, December 1985.

6. Tatken, R.L. and Lewis, R.J. (ed.). Registry of Toxic Effects of Chemical Substances, (RTECS). 1981-82 edition, 3 volumes, NIOSH Contract No. 210-81-8101, DHHS (NIOSH) Publication No. 83-107, June 1983.

7. U.S. Patent No. 3,360,335.

8. U.S. Patent No. 3,718,731.

9. U.S. Patent No. 3,104,945.

10. U.S. Patent No. 3,215,495.

11. U.S. Patent No. 2,680,761.

12. U.S. Patent No. 3,496,215.

13. U.S. Patent No. 3,536,748.

14. Lawler, G.M. (ed.). Chemical Origins and Markets. Fifth Edition, Chemical Information Services, Stanford Research Institute, 1977.

15. Methyl Methacrylate, 1983 Petrochemical Handbook Issue. Hydrocarbon Processing, Gulf Publishing Company, Houston, TX, November 1983.

16. Methyl Methacrylate, 1979 Petrochemical Handbook Issue. Hydrocarbon Processing, Gulf Publishing Company, Houston, TX, November 1979.

17. U.S. Patent No. 2,537,814.

18. Strong Outlook for Cyanuric Chloride. Chemical and Engineering News, July 26, 1976.

19. U.S. Patent No. 2,762,798.

20. U.S. Patent No. 2,993,754.

21. HCN Safety Symposium. E.I. DuPont DeNemours and Company, Memphis, TN.

22. McNaughton, K.J. (ed.). Materials Engineering I: Selecting Materials for Process Equipment. McGraw-Hill Publications Company, New York, NY, 1980.

23. Metals Handbook Ninth Edition, Volume 3. American Society for Metals, Metals Park, OH, 1980.

24. Harper, C.A. (ed.). Handbook of Plastics and Elastromers, McGraw-Hill Book Company, New York, NY, 1975.

25. Telephone conversation between D.S. Davis of Radian Corporation and a representative of Monsanto Corporation. St. Louis, MO, January 1987.

26. Green, D.W. (ed.). Perry's Chemical Engineer's Handbook, 6th edition, McGraw-Hill Book Company, New York, NY, 1984.

27. Telephone conversation between D.S. Davis of Radian Corporation and a representative of E.I. DuPont DeNemours and Company. Memphis, TN, January 1987.

28. Lewis, D.J. The Mond Fire, Explosion and Toxicity Index Applied to Plant Layout and Spacing. Loss Prevention, Volume 13, American Institute of Chemical Engineers, 1980.

29. Lees, Frank P. Loss Prevention in the Process Industries, Volumes 1 & 2, Butterworths, London, England, 1983.

30. Federal Register. Volume 50. April 16, 1985. pp. 14,941-14,945.

31. Pohl, J.H. and Soelberg, N.R. Evaluation of the Efficiency of Industrial Flares: Flare Head Design and Gas Composition. EPA-600/2-85-106 (NTIS PB86-100559), Energy and Environmental Research Corporation, September 1985.

32. Radian Notebook No. 215. EPA Contract 68-02-3994. Work Assignment 94, Page 5, 1986.

33. Darts, J.J. and D.M. Morrison. Refrigerated Storage Tank Retainment Walls. Chemical Engineering Progress Technical Manual, Volume 23, American Institute of Chemical Engineers, New York, NY, 1981.

34. Beresford, T.C. The Use of Water Spray Monitors and Fan Sprays for Dispersing Gas Leakage. I. Chem. E. Symposium Proceeding. The Containment and Dispersion of Gases by Water Sprays, Manchester, England, 1981.

35. McQuaid, J. and A.F. Roberts. Loss of Containment - Its Effect and Control, in Developments '82 (I. Chem. E. Jubilee Symposium). London, England, April 1982.

36. Chemical Manufacturers Association. Process Safety Management (Control of Acute Hazards). Washington, DC, May 1985.

37. Stus, T.F. On Writing Operating Instructions. Chemical Engineering, November 26, 1984.

38. Burk, A.F. Operating Procedures and Review. Presented at the Chemical Manufacturers Association Process Safety Management Workshop. Arlington, VA, May 7-8, 1985.

39. Peters, M.S. and K.D. Timmerhaus. Plant Design and Economics for Chemical Engineers. McGraw-Hill Book Company, New York, NY, 1983.

40. Richardson Engineering Services, Inc. The Richardson Rapid Construction Cost Estimating System, Volume 1-4, San Marcos, CA, 1986.

41. Pikulic, A. and H.E. Diaz. Cost Estimating for Major Process Equipment. Chemical Engineering, October 10, 1977.

42. Hall, R.S., J. Matley, and K.J. McNaughton. Cost of Process Equipment. Chemical Engineering, April 5, 1982.

43. Yarmartino, J. Installed Cost of Corrosion - Resistant Piping. Chemical Engineering, November 20, 1978.

44. Telephone conversation between J.D. Quass of Radian Corporation and a representative of Mark Controls Corporation. Houston, TX, August 1986.

45. Telephone conversation between J.D. Quass of Radian Corporation and a representative of Fike Corporation. Houston, TX, August 1986.

46. R.S. Means Company, Inc. Building Construction Cost Data, (44th Ed.) Kingston, MA, 1986.

47. Liptak, B.G. Cost of Process Instruments. Chemical Engineering, September 7, 1970.

48. Liptak, B.G. Control - Panel Costs, Process Instruments. Chemical Engineering, October 5, 1970.

49. Vatavuk, W.M. and R.B. Neveril. Cost of Flares. Chemical Engineering, February 21, 1983.

50. Green, D.W. (ed.). Perry's Chemical Engineers' Handbook (Sixth Edition). McGraw-Hill Book Company, New York, NY, 1984.

51. Cost indices obtained from Chemical Engineering. McGraw-Hill Publishing Company, New York, NY, June 1984, December 1985, and August 1986.

52. Valle-Riestra, J.F. Project Evaluation in the Chemical Process Industries. McGraw-Hill Book Company, New York, NY, 1983.

APPENDIX A
GLOSSARY

This glossary defines selected terms used in the text of this manual which might be unfamiliar to some users or which might be used differently by different authors.

Accidental release: The unintentional spilling, leaking, pumping, purging, emitting, emptying, discharging, escaping, dumping, or disposing of a toxic material into the environment in a manner that is not in compliance with a plant's federal, state, or local environmental permits and results in toxic concentrations in the air that are a potential health threat to the surrounding community.

Assessment: The process whereby the hazards which have been identified are evaluated in order to provide an estimate for the level of risk.

Containment/control: A system to which toxic emissions from safety relief discharges are routed to be controlled. A caustic scrubber and/or flare can be containment/control devices. These systems may serve the dual function of destructing continuous process exhaust gas emissions.

Enthalpy: A thermodynamic property of a chemical related to its energy content at a given condition of temperature, pressure and physical state. Enthalpy is the internal energy added to the product of pressure times volume. Numerical values of enthalpy for various chemicals are always based on the change in enthalpy from an arbitrary reference pressure and temperature, and physical state, since the absolute value cannot be measured.

Facility: A location at which a process or set of processes are used to produce, refine or repackage chemicals, or a location where a large enough inventory of chemicals are stored so that a significant accidental release of a toxic chemical is possible.

Hazard: A source of danger. The potential for death, injury or other forms of damage to life and property.

Identification: The recognition of a situation, its causes and consequences relating to a defined potential, e.g. Hazard Identification.

Mild steel: Carbon steel containing a maximum of about 0.25% carbon. Mild steel is satisfactory for use where severe corrodants are not encountered or where protective coatings can be used to prevent or reduce corrosion rates to acceptable levels.

Mitigation: Any measure taken to reduce the severity of the adverse effects associated with the accidental release of a hazardous chemical.

Passivation film: A layer of oxide or other chemical compound of a metal on its surface that acts as a protective barrier against corrosion or further chemical reaction.

Plant: A location at which a process or set of processes are used to produce, refine, or repackage, chemicals.

Prevention: Design and operating measures applied to a process to ensure that primary containment of toxic chemicals is maintained. Primary containment means confinement of toxic chemicals within the equipment intended for normal operating conditions.

Primary Containment: The containment provided by the piping, vessels and machinery used in a facility for handling chemicals under normal operating conditions.

Probability/potential: A measure, either qualitative or quantitative, that an event will occur within some unit of time.

Process: The sequence of physical and chemical operations for the production, refining, repackaging or storage of chemicals.

Process machinery: Process equipment, such as pumps, compressors, heaters, or agitators, that would not be categorized as piping and vessels.

Protection: Measures taken to capture or destroy a toxic chemical that has breached primary containment, but before an uncontrolled release to the environment has occurred.

Qualitative Evaluation: Assessing the risk of an accidental release at a facility in relative terms; the end result of the assessment being a verbal description of the risk.

Quantitative Evaluation: Assessing the risk of an accidental release at a facility in numerical terms; the end result of the assessment being some type of number reflects risk, such as faults per year or mean time between failure.

Reactivity: The ability of one chemical to undergo a chemical reaction with another chemical. Reactivity of one chemical is always measured in reference to the potential for reaction with itself or with another chemical. A chemical is sometimes said to be "reactive", or have high "reactivity", without reference to another chemical. Usually this means that the chemical has the ability to react with common materials such as water, or common materials of construction such as carbon steel.

Redundancy: For control systems, redundancy is the presence of a second piece of control equipment where only one would be required. The second piece of equipment is installed to act as a backup in the event that the primary piece of equipment fails. Redundant equipment can be installed to backup all or selected portions of a control system.

Risk: The probability that a hazard may be realized at any specified level in a given span of time.

Secondary Containment: Process equipment specifically designed to contain material that has breached primary containment before the material is released to the environment and becomes an accidental release. A vent duct and scrubber that are attached to the outlet of a pressure relief device are examples of secondary containment.

Toxicity: A measure of the adverse health effects of exposure to a chemical.

APPENDIX B

TABLE B-1. METRIC (SI) CONVERSION FACTORS

Quantity	To Convert From	To	Multiply By
Length:	in	cm	2.54
	ft	m	0.3048
Area:	in^2	cm^2	6.4516
	ft^2	m^2	0.0929
Volume:	in^3	cm^3	16.39
	ft^3	m^3	0.0283
	gal	m^3	0.0038
Mass (weight):	lb	kg	0.4536
	short ton (ton)	Mg	0.9072
	short ton (ton)	metric ton (t)	0.9072
Pressure:	atm	kPa	101.3
	mm Hg	kPa	0.133
	psia	kPa	6.895
	psig	kPa*	[(psig)+14.696] x(6.895)
Temperature	°F	°C*	(5/9)x(°F-32)
	°C	K*	°C+273.15
Caloric Value; Enthalpy:	Btu/lb	kJ/kg	2.326
	Btu/lbmol	kJ/kgmol	2.326
	kcal/gmol	kJ/kgmol	4.184
Specific-Heat Capacity:	Btu/lb-°F	kJ/kg-°C	4.1868
Density:	lb/ft^3	kg/m^3	16.02
	lb/gal	kg/m^3	119.8
Concentration:	oz/gal	kg/m^3	7.490
	quarts/gal	cm^3/m^3	25,000
Flowrate:	gal/min	m^3/min	0.0038
	gal/day	m^3/day	0.0038
	ft^3/min	m^3/min	0.0283
Velocity:	ft/min	m/min	0.3048
	ft/sec	m/sec	0.3048
Viscosity:	centipoise (CP)	kg/m-s	0.001

*Calculate as indicated.